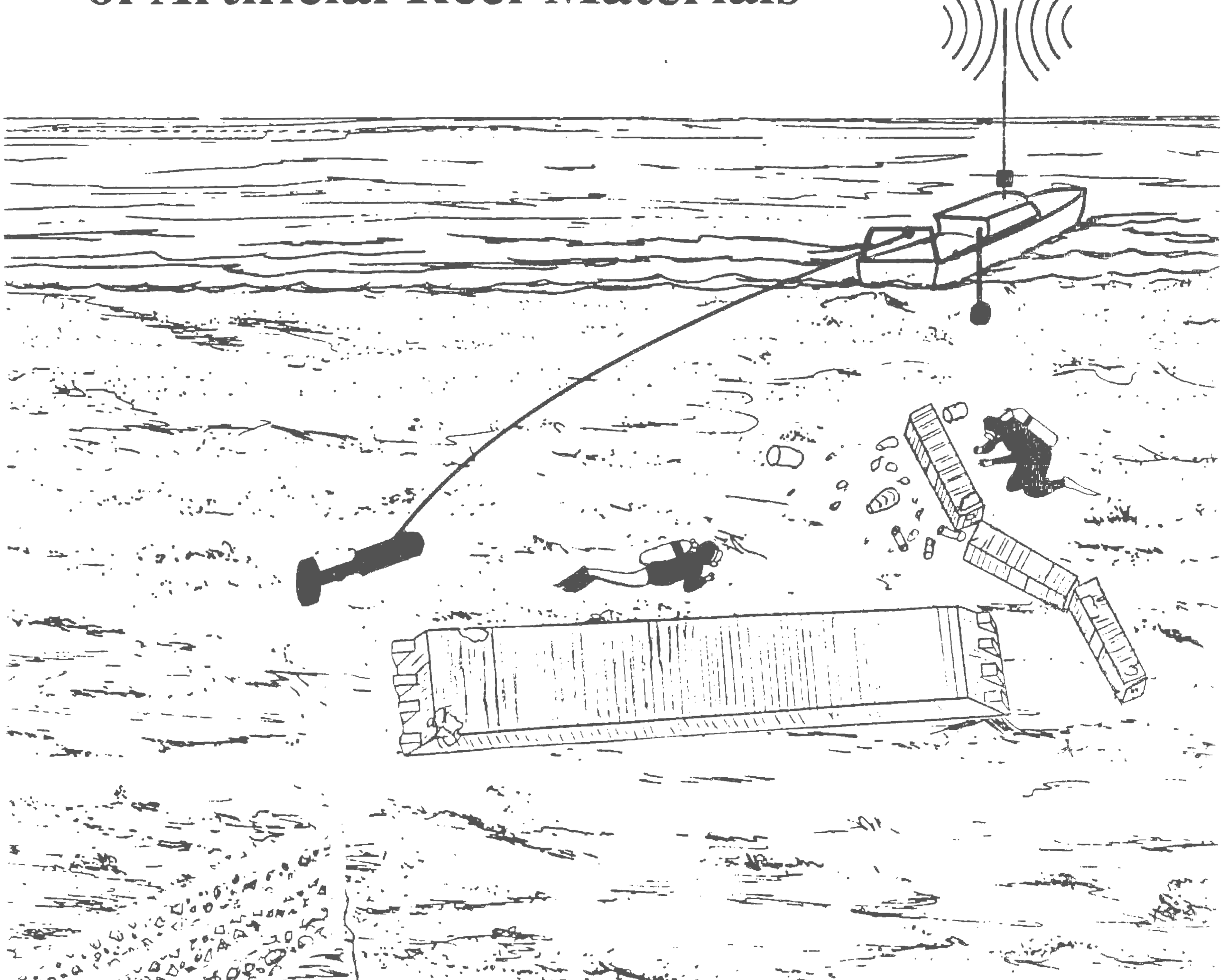
Two Methods of Monitoring and Assessment of Artificial Reef Materials



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TWO METHODS OF MONITORING AND ASSESSMENT OF ARTIFICIAL REEF MATERIALS

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DEDICATION

This publication is dedicated to the memory of Mr. Joe Pollio who died unexpectedly during the course of preparing the data from the side scan sonar portion of this study. Joe Pollio will be remembered as a consumate professional and a good friend.

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INTRODUCTION

Background on Artificial Reef Development in the United States

The concept of the artificial reef is not a new one. Man-made reefs have been in existence in the United States since the early 1800's (Stone 1978). Until recently, it was not recognized that proper planning and siting of artificial reefs was vital to a successful reef and program (Mathews 1981). Materials and designs used to build reefs have also undergone some advances, from early reefs using trees (Stone 1978) to the Japanese technology using manufactured structures (Sheehy 1983).

As artificial reef development intensified, it became evident that management responsibilities of maintenance, monitoring, and evaluation were important aspects of artificial reef development which should not be ignored. This concept was formalized by Stone (1985) in the National Artificial Reef Plan which was mandated by the 1984 National Fishing Enhancement Act passed by Congress. Though early efforts at artificial reef construction were accomplished primarily by private groups or individuals, more recently state and local governments have begun to accept the responsibility of artificial reef construction and management, although there are many private groups that are still active. Among the probable reasons for government involvement are the potential for adverse impacts of artificial reefs on the the environment and competing user groups, the increasing complexity of artificial reef construction and management, the potential for use of artificial reefs as management tools, and liability concerns.

Though it has long been known that artificial reefs attract and hold populations of fish and improve fishing success (Idyll and Randall 1959 and Kumph and Randall 1961), it is only recently that the concept of artificial reefs as a fishery management tool has gained serious consideration (Haughton and Aiken 1987). The widespread construction of artificial reefs has caused some concern by environmentalists and resource managers over issues such as the potential to overfish stocks of fish associated with reef structures, contamination of the natural habitat with man-made material, liability, and the lack of coordination, planning and management within artificial reef programs. At an international conference in Miami, Florida in 1987 it was emphasized that the future success of artificial reef utilization in the United States depends on responsible reef planning, development and management, recognizing both the capabilities and limitations of artificial reefs in fisheries (Seaman and Welch, 1988).

Background on Artificial Reef Development in Mississippi

In the 1960's, the first documented artificial reef was created offshore of Horn Island, Mississippi using car bodies. Though this reef increased fishing success for a short period of time, the car bodies were not durable enough to withstand the harsh marine environment, and they soon deteriorated. It was not until 1972, when the federal government made retired Liberty ships available to coastal states, that Mississippi again became seriously involved in artificial reefs.

Through the Mississippi Marine Conservation Commission, Mississippi received title to five Liberty ships for the purpose of building artificial reefs. By 1978 all five ship hulls had been prepared and scuttled, creating two artificial reefs offshore of Mississippi. Since that time, a total of seven artificial reef sites have been permitted and developed, encompassing approximately 1,826 acres of bottom.

Beginning in 1975 a three year project of biological monitoring was conducted on one of the offshore artificial reef sites through the efforts of the Mississippi-Alabama Sea Grant Consortium, the Dauphin Island Sea Lab, and the Gulf Coast Research Laboratory (Lukens 1980). From 1978 through 1984 no monitoring of any kind took place. In 1984, the Mississippi Gulf Fishing Banks, Inc. (the organization holding the permits for all artificial reefs offshore of Mississippi), through a cooperative effort with the Mississippi Cooperative Extension Service, began a program to develop guidelines for monitoring the physical parameters of Mississippi's offshore artificial reefs (Lukens and Cirino 1985). Those guidelines have provided the basis for a continuing program to monitor artificial reef materials offshore of Mississippi.

Justification and Need

According to Stone (1985) there are two primary reasons for establishing monitoring programs as a part of overall reef management. The first is for compliance, an implied mandatory activity which assures that artificial reefs comply with permits allowing reef construction. The second is performance assessment and evaluation which is to determine whether or not a reef is accomplishing its desired purpose(s). This includes monitoring the biota. Both aspects of monitoring are vital to an artificial reef manager in order to maintain compliance with the law and maintain a cost effective artificial reef program.

For monitoring and assessment of artificial reef materials, activities can be divided into three categories: (a) determination of accurate LORAN-C coordinates and orientation of materials, (b) determination of the degree and rate of subsidence of materials, and (c) determination of the degree of deterioration of materials over time.

Initially, the determination of accurate LORAN-C coordinates and orientation is necessary so that materials can be accurately charted for navigational purposes and to allow fishermen to locate reef materials. Secondly, by updating LORAN coordinates and orientations, reef managers will be able to detect if any shifting or major movement of reef materials has occurred.

By maintaining accurate measurements of the height of reef materials above the bottom, reef managers are able to detect any degree of subsidence. Water clearance above reef materials is important from a navigational standpoint.

Finally, the marine environment is dynamic, with tidal fluctuations, temperature changes, current flow, marine animals and the saltwater medium all contributing to the deterioration of man-made materials. It is important to monitor the rate and extent of deterioration of reef materials so that future construction efforts can be as efficient and effective as possible.

In general, monitoring and assessment of artificial reef materials should be an integral part of any ongoing reef program. It is an activity which will aid in the effectiveness of artificial reefs in attracting and maintaining fish populations and contribute to the long term effectiveness of reef materials by providing reef managers with information on the suitability of bottom types and materials.

OBJECTIVE

The objective of this study is to compare the capabilities and limitations of two methods of monitoring and assessment of artificial reef materials, first using Self Contained Underwater Breathing Apparatus (SCUBA) and second using side scan sonar. Specific points of interest addressed are:

A) Accurate LORAN-C coordinates for all materials at each reef site.

B) Accurate water depth and height of reef material above the bottom.

C) Composition and orientation of structures.

D) Physical condition of present materials regarding effects of exposure, subsidence, and scattering.

METHODS AND MATERIALS

The two methods employed during this study were a SCUBA method devised by Lukens and Cirino (1985) and a survey using side scan sonar. Five artificial reef sites located offshore of the Mississippi barrier islands were surveyed using both techniques. Replicates were not acquired; however, historical data describing the sites does exist (Lukens and Cirino 1985 and 1986).

SCUBA Survey

LORAN-C coordinates for each piece of reef material surveyed were acquired by divers using SCUBA who placed inflatable buoys on the bow and stern of each ship hull or barge and recorded the coordinates on the surface at each buoy location using a Si-Tex 787 LORAN-C unit.

Water depth at each site was measured using a Si-Tex HE-32 MK II chart type depth recorder. Height of reef materials over the bottom were measured by two divers using SCUBA. One diver held one end of a 50 foot tape measure at the top of the reef structure while the other diver pulled the other end of the tape to the substrate. Bow, stern, and midship measurements were made on the Liberty ship hulls, while the four corners of the bow and stern of barges were measured. The results were recorded on organically coated, underwater paper using a standard #2 graphite pencil.

Composition and orientation of reef structures on each artificial reef site were accomplished by plotting the LORAN-C coordinates on LORAN-C plats of each artificial reef site. Graphic representations of barge and ship hulls contained in this report may exhibit some inconsistencies in lengths of the various hulls surveyed. This is due to the error inherent in LORAN-C receiving equipment coupled with the varying tidal and surface wave effects on small surface buoys.

General condition of ship and barge hulls was recorded on organically coated, underwater paper while divers using SCUBA conducted general observation surveys of various materials.

Side Scan Sonar Survey

Equipment

Side scan sonars use high-frequency energy waves transmitted at an oblique angle to the sea floor which are reflected by solid objects on the sea floor. Reflected energy waves can be detected and the time difference between transmitted and reflected pulses can be measured. Time differences between transmitted and reflected pulses multiplied by the speed of sound in water is the slant range to the reflector. If the position of the side scan sonar transceiver is known, the position of the reflector can be geometrically determined. Relief of about one wavelength of the transmitted energy divided by eight times the cosine of the angle of incidence is detectable.

Equipment required to collect side scan sonar records includes a transducer tow body to generate outgoing signals and detect returning signals, a line scan or other recorder to store reflected signals, and a navigation system to relate the known position of the tow ship to the unknown position of the target. When transducers are mounted on either side of a tow body, the side scan sonar records a transect of the sea bottom from a center line representing the path of the ship and tow body. The width of the transect depends on the frequency of the transducer, the radiated power of the transducer, the water depth, and the height of the transducer above the sea floor.

To conduct the side scan sonar portion of the study, the R/V BILL DEMORAN was outfitted with an EG&G Side Scan Sonar System. The sonar provided a near plane-view image of the sea floor and objects lying on it along an area up to approximately 2,000 feet wide.

Ship's position was determined at one minute intervals with a Si-Tex LORAN-C receiver and plotted on LORAN charts prepared by the Gulf States Marine Fisheries Commission for this purpose. All LORAN-C coordinates within this report were derived from the LORAN-C GRI of 7980 using the W and Y axes.

Straight-line speed was maintained as near 4 kn (6.56 ft/sec) as possible; steering was by magnetic compass. Nominal transducer tow depth was 10 feet, although actual transducer depth was a function of ship's true speed and heading with respect to sea.

Sources of Distortion

Side scan sonar imagery may be distorted by transducer pitch, roll, heave, or yaw caused by surface conditions. Transducer motions can be reduced by proper tow body design, operating during favorable weather, reducing tow speeds to a practical minimum, or decoupling boat motion from the tow body.

Positions were determined by LORAN-C and a chart-reading depth recorder. A LORAN-C timing error of 100nsec (10^{-7} seconds) will cause a position error of 49 feet or about 0.1 unit on the 124 LORAN rates. Navigational discrepancies may be caused by antenna motion due to ship roll or imprecise monitoring of ship's speed. The side scan transducer is towed some distance behind the LORAN-C receiving antenna and this distance must be estimated from ship speed, wire angle, and the amount of cable deployed.

Transducer height above the bottom and speed through the water are required to correct side scan record distortions and determine the true position and relief of an object on the bottom. In the absence of a continuously-recording pit log, boat operators estimate speed based on previous experience, engine RPM, and navigation. These methods lack precision for adequately plotting exact target locations and sizes. For example, an undetected speed increase of 0.5 kn will distort the length of a 330 foot ship by more than 40 feet. Record distortions occur because the along-track scale is a function of boat speed while the across-track scale is independent of boat speed. Corrections for and estimates of these distortions were applied in analyzing the side scan records acquired during this study.

DESCRIPTION OF STUDY SITES

Oceanographic Background

All artificial reef sites surveyed in this study are located in an area where surface salinities range between 12 0/00 and 33 0/00 depending on freshwater runoff. Bottom-water salinities range between 32 0/00 and 36 0/00. Similarly, surface temperatures range between 14° C and 28° C and do not change significantly with depth except during transitional periods.

Currents are driven by both winds and tides with occasional modification by water-column stratification. Tidal currents are diurnal and rotary; as the current flows continuously, the direction rotates clockwise once over a 24.8h period. Average peak tidal speeds (occurring every 12.4h) range from 0.2 to 0.6 kn. Peak near-bottom tidal current speeds are nearly equal to surface current speeds. During periods of light winds, tidal current dominates. Winds with velocities greater that 15kn can mask tidal rotation at all depths. Large seasonal changes in currents are weakest from May through September, when winds are generally less than 8kn. From November through March, strong winds associated with the passage of low air pressure systems (cyclonic fronts) cause a significant increase in current speed. Typical near-bottom current speeds during a frontal passage are 0.7kn but can reach 1.0kn. Most of the bottom scouring around various reefs probably occurred during the very short time encompassing a frontal passage.

The oceanic environment surrounding the reefs is conducive to heavy accumulations of marine organisms on exposed metal surfaces. Accretion rates of 1 to 1-$\frac{1}{4}$ in/yr are not unusual. The most abundant biofouling species are barnacles and hydroids with maximum growth rates occurring during spring and summer.

Artificial Reef Sites (Figure 1)

FH-1: This artificial reef site encompasses 307.25 acres of sea bottom approximately nine miles south of the east end of Horn Island off Mississippi. Water depth at this site is approximately 70 feet. The LORAN-C coordinates for the four corners of the site are:

Northwest Corner - 12403.6/47039.0
Southwest Corner - 12403.6/47035.2
Northeast Corner - 12408.3/47039.0
Southeast Corner - 12408.3/47035.2

According to Jones, et. al. (1986), the predominant bottom sediment at FH-1 is sand; however, some isolated pockets of silty clay are present.

FH-3: This artificial reef site encompasses 9.8 acres of sea bottom, and lies approximately 4.5 miles south of the west end of Horn Island off Mississippi. Water depth at this site is approximately 45 feet. The LORAN-C coordinates for the four corners of the site are:

Northwest Corner - 12319.0/47061.6
Southwest Corner - 12319.0/47061.3
Northeast Corner - 12320.0/47061.6
Southeast Corner - 12320.0/47061.3

Jones, et. al. (1986) report silty clay is the predominant bottom sediment type here.

FH-4: This artificial reef site encompasses one acre of sea bottom and lies about 3.5 miles south of the west end of the eastern section of Ship Island off Mississippi. Water depth at that site is approximately 30 feet. The LORAN-C coordinates for the four corners of the site are:

Northwest Corner - 12227.1/47061.3
Southwest Corner - 12227.1/47061.2
Northeast Corner - 12227.5/47061.3
Southeast Corner - 12227.5/47061.2

General observations on the FH-4 indicate that the predominant bottom sediment type is silty clay (Lukens 1980).

Figure 1. Locations of the five artificial reef sites surveyed by both the SCUBA and side scan sonar methods.

FH-5: This artificial reef site, like FH-4, encompasses one acre of sea bottom and lies approximately 4.0 miles south of the east end of the eastern section of Ship Island off Mississippi. Water depth at that site is approximately 30 feet. The LORAN-C coordinates for the four corners of the site are:

Northwest Corner - 12263.9/47063.2
Southwest Corner - 12263.9/47063.1
Northeast Corner - 12264.3/47063.2
Southeast Corner - 12264.3/47063.1

The bottom sediment type at this site is similar to that reported for FH-4, which is silty clay (Lukens 1980).

FH-6: This artificial reef site encompasses approximately 22 acres of sea bottom and lies approximately 12 miles south of the west end of Horn Island off Mississippi. The water depth is approximately 65 feet. LORAN-C coordinates for the four corners of the site are:

Northwest Corner - 12354.9/47031.0
Southwest Corner - 12354.9/47030.2
Northeast Corner - 12356.9/47031.0
Southeast Corner - 12356.9/47030.2

According to Jones, et. al. (1986), the predominant bottom sediment type at this site is silty clay.

RESULTS

This section presents the data which were collected using both the SCUBA and side scan sonar surveys. All target designations for both surveys are the same. All charts and figures resulting from both surveys are found in Appendix 1.

SCUBA SURVEY

Using SCUBA, divers conducted surveys on each artificial reef included in this study to assess position, elevation off the bottom, and general condition. Table 1 provides LORAN-C coordinates for each target surveyed.

FH-1: Two separate targets within the FH-1 site were surveyed. The first target, designated Barge A, lies in approximately 70 feet of water (Figure 2). Table 2 provides measurements of the four corners of the barge indicating elevation above bottom. Minimum clearance above Barge A is approximately 58 feet. Barge A is a deck barge measuring 175' long, 73' wide, and 12' high and lies upright on the bottom. There is very little deterioration of the barge, limited to oxidation, and minimal scouring around the outer edge. The stern of the barge orients towards the northeast at approximately 45°.

Due to high sea conditions target Barge B on FH-1 was not surveyed using SCUBA. The second target is designated as Barge C and also lies in approximately 70 feet of water (Figure 3). Measurements of the barge (Table 2) indicate a minimum clearance above the structure of 62 feet. Barge C is a hopper barge which lies upside down and measures 280' long, 50' wide, and 15' high. Deterioration is minimal. Large holes resulting from dynamite charges used to sink the barge are evident, with the most notable occurring on the north (starboard) side near the bow. The bow of the barge orients towards the east at approximately 95°. There is a scoured trench along the north side of the barge approximately 3' wide and 3' deep. Part of the rake end of the bow is buried in the bottom.

The contents of Barge C, consisting of four railroad boxcars and assorted concrete rubble, were spilled out of the hopper during sinking. The boxcars and rubble lie east of Barge C. One boxcar lies adjacent to

Table 1. LORAN-C Coordinates for Major Components of Artificial Reef Sites FH-1, FH-3, FH-4, FH-5 and FH-6 Using Data From SCUBA and Side Scan Sonar Survey Methods (LORAN-C GRI 7980, Lines W and Y).

SITE	TARGET	SCUBA COORDINATES	COMMENTS	SIDE SCAN COORDINATES	COMMENTS
FH-1	A (Barge)	12405.8; 47037.1	Bow (Midline)	12405.71; 47037.18	Corners of
		12406.4; 47037.3	Stern (Midline)	12405.81; 47037.16	Barge
				12405.93; 47037.27	
				12406.03; 47037.24	
	B (Barge)	N/A	N/A	12407.73; 47038.23	Corners of
				12407.71; 47038.24	Barge
				12407.71; 47038.33	
				12407.65; 47038.33	
	C (Barge)	12405.9; 47035.6	Bow (Midline)	12405.38; 47035.63	Midline of
		12405.5; 47035.6	Stern (Midline)	12405.84; 47035.63	Barge
		12406.1; 47035.6	Railroad Boxcar	N/A	N/A
		12406.0; 47035.5	Railroad Boxcar	N/A	N/A
FH-3	A (Liberty	12319.8; 47061.6	Bow	12319.66; 47061.47	Bow
	Ship)	12319.9; 47061.3	Stern	12319.05; 47061.65	Stern
	B (Liberty	12319.6; 47061.5	Bow	12319.94; 47061.67	Bow
	Ship)	12319.0; 47061.6	Stern	12320.10; 47061.39	Stern
FH-4	A (Barge)	12227.5; 47061.3	Bow (Midline)	12227.27; 47061.41	Corners of
		12227.3; 47061.3	Stern (Midline)	12227.35; 47061.42	Barge
				12227.41; 47061.31	
				12227.49; 47061.32	
	B (Barge)	12227.6; 47061.3	Bow (Midline)	N/A	N/A
		12227.4; 47061.3	Stern (Midline)	N/A	N/A

Table 1. Continued.

SITE	TARGET	SCUBA COORDINATES	COMMENTS	SIDE SCAN COORDINATES	COMMENTS
FH-5	(Barge)	12264.0; 47063.2	Bow (Midline)	12264.02; 47063.34	Corners of
		12264.4; 47063.2	Stern (Midline)	12264.09; 47063.32	Barge
				12263.71; 47063.25	
				12263.77; 47063.23	
FH-6	A (Liberty	12356.1; 47030.7	Bow	12356.13; 47031.03	Bow
	Ship)	12356.1; 47031.0	Stern	12356.13; 47030.71	Stern
	B1	12355.9; 47030.8	Midship (Starboard)	12356.05; 47030.95	Midship (Starboard)
	(½ Hull)	12356.1; 47030.8	Stern	12356.04; 47030.77	Stern
	B2	12355.6; 47030.5	Bow	N/A	Incorrectly
	(½ Hull)	12355.8; 47030.6	Midship (Starboard)	N/A	Identified
	C1	12356.1; 47030.4	Bow	12355.80; 47030.25	Bow
	(½ Hull)	12355.6; 47030.6	Midship (Starboard)	12355.50; 47030.35	Midship (Starboard)
	C2	12355.1; 47030.1	Midship (Starboard)	12355.42; 47030.29	Midship (Starboard)
	(½ Hull)	12354.9; 47030.3	Stern	12354.95; 47030.46	Stern
	D	12355.9; 47030.8	Bow (Port)	12356.00; 47030.57	Incorrectly
	(Barge)	12355.9; 47030.7	Stern (Port)	12356.10; 47030.60	Identified as the
				12355.57; 47030.41	B2 Target

Table 2. Vertical Heights of Artificial Reef Materials Measured Using SCUBA and Estimated From the Side Scan Sonar Survey (Feet and Inches).

SITE	TARGET	SCUBA MEASUREMENTS	COMMENTS	SIDE SCAN ESTIMATES	COMMENTS
FH-1	A (Barge)	11'7"	Bow (Starboard)	Approximately 10'0"	No Designation
		10'9"	Bow (Port)		
		12'0"	Stern (Starboard)		
		12'4"	Stern (Port)		
	B (Barge)	N/A	N/A	N/A	N/A
	C (Barge)	7'4"	Bow (Starboard)	4' - 8'	No Designation
		8'1"	Bow (Port)		
		3'6"	Stern (Starboard)		
		4'7"	Stern (Port)		
	Railroad Boxcar	9'6"	1st End	N/A	N/A
	Railroad Boxcar	8'8"	2nd End	N/A	N/A
	Railroad Boxcar	9'7"	1st End	N/A	N/A
	Railroad Boxcar	12'2"	2nd End	N/A	N/A
FH-3	A (Liberty Ship)	11'4"	Bow	$\leq$ 10'0"	No Designation
		13'1"	Midship (Starboard)		
		12'11"	Midship (Port)		
		10'10"	Stern		
	B (Liberty Ship)	8'10"	Bow	$\leq$ 10'0"	No Designation
		12'10"	Midship (Starboard)		
		12'4"	Midship (Port)		
		9'5"	Stern		

Table 2. Continued.

SITE	TARGET	SCUBA MEASUREMENTS	COMMENTS	SIDE SCAN ESTIMATES	COMMENTS
FH-4	A	5'2"	Bow (Starboard)	N/A	N/A
	(Barge)	5'3"	Bow (Port)		
		8'3"	Stern (Starboard)		
		8'3"	Stern (Port)		
	B	2'2"	Bow (Starboard)	N/A	N/A
	(Barge)	2'6"	Bow (Port)		
		1'0"	Stern (Starboard)		
		2'4"	Stern (Port)		
FH-5	(Barge)	5'11"	Bow (Starboard)	< 7'0"	No Designation
		7'10"	Bow (Port)		
		3'8"	Stern (Starboard)		
		8'6"	Stern (Port)		
FH-6	A (Liberty	3'9"	Bow	< 10'0"	No Designation
	Ship)	10'10"	Midship (Starboard)		
		N/A[1]	Midship (Port)		
		0'0"	Stern		
	B1	10'8"	Midship (Starboard)	N/A	N/A
	(½ Hull)	9'6"	Midship (Port)		
		N/A[2]	Stern		
	B2	0'0"	Bow	N/A	N/A
	(½ Hull)	10'10"	Midship (Starboard)		
		11'7"	Midship (Port)		

Table 2. Continued.

SITE	TARGET	SCUBA MEASUREMENTS	COMMENTS	SIDE SCAN ESTIMATES	COMMENTS
	C1	10'11"	Bow	N/A	N/A
	(½ Hull)	15'4"	Midship (Starboard)		
		11'8"	Midship (Port)		
	C2	12'0"	Midship (Starboard)	N/A	N/A
	(½ Hull)	14'7"	Midship (Port)		
		6'8"	Stern		
	D	N/A[1]	Bow (Starboard)	N/A	N/A
	(Barge)	6'10"	Bow (Port)		
		N/A[1]	Stern (Starboard)		
		12'7"	Stern (Port)		

1 Barge D lies alongside the port side of target A.

2 The stern of target D rests on top of the stern section of target B1.

the north end of the barge bow. It lies upside down and slightly tilted towards the east in a scoured depression. The axis of the boxcar orients north and south and is almost perpendicular to Barge C. The other three boxcars lie approximately 70-100 feet east of the barge bow. All three boxcars are adjacent and upright. The concrete rubble is concentrated in the vicinity of the three adjacent boxcars. All boxcars show minimal deterioration and scouring.

FH-3: Two separate targets, scrapped Liberty ship hulls (Figure 4), were surveyed at FH-3. The first ship hull, designated A, lies in approximately 45 feet of water. Measurements (Table 2), including the bow, midship (port and starboard), and stern, indicate a minimum clearance above the hull of approximately 32 feet.

The second target, designated B, lies 150 to 200 feet west of target A in approximately 45 feet of water. Measurements (Table 2) indicate a minimum clearance of approximately 32 feet above the ship hull. The bow of hull A orients towards the north at approximately 352°. The stern of hull B orients towards the west-northwest at approximately 290°. Each hull measures approximately 476' long, 56' wide, and 15' high. There is minimal scouring around the hulls and it is confined to the ends of each hull. There has been some deterioration on each hull. Besides "flaking", cracks proceeding from the port side, down along the hull bottom, and up the starboard side at midship have been noted on both hulls. These are probably a result of the original construction design (each ship was built in halves and the halves welded together) and the sinking process (the stern section of each ship was flooded and came to rest on the bottom first; observers noted loud "pops" as each hull sank). The firebrick boilers in the engine rooms of both hulls have collasped as have some bulkheads.

Several baled tire units originally attached in the ship hulls prior to sinking have deteriorated or altogether disappeared. Individual tires are scattered within the hulls and occur mainly between the bases of the ship's gussets (ribs). Several shrimp trawls have become entangled on both ship hulls.

FH-4: FH-4 consists of two barges, designated A and B (Figure 5), and has an approximate water depth of 35 feet. Measurements of Barge A

(Table 2) indicate a minimum clearance of approximately 27 feet. Barge B, a smaller target, has a minimum clearance of approximately 33 feet, derived from the measurements (Table 2).

Barge A is a hopper barge measuring 195' long, 35' wide, and 12' high. Barge B is a deck barge measuring 120' long, 30' wide, and 7' high. Both barges lie upright on the bottom. The stern of barge A orients towards the west-northwest at approximately 300°. The stern of barge B orients towards the west-northwest at 290°. The starboard stern corner of barge B lies adjacent to the port side of barge A just forward of the stern. Barge A contains several concrete pilings and two concrete tresses. The pilings are located in the stern section of the hopper. The larger concrete tress is located just aft of the center and the smaller one is located near the bow section of the hopper.

There has been minimal deterioration ("flaking") of both barges and concrete materials. Damage from dynamite charges used on barge A are evident but were not noted on barge B. There is some trench scouring around the outer edges of A and B on the north side where they meet.

FH-5: FH-5 consists of one barge which lies in approximately 35 feet of water (Figure 6). Table 2 provides measurements of the four corners of the barge, indicating a minimum clearance of 27 feet.

The barge at FH-5 measures 195' long, 35' wide, and 12' high and is a hopper barge. It contains several waste dumpsters located near the bow. The stern of the barge orients towards the northeast at approximately 45°. There is a large "blow hole" from the dynamite charge near the port bow. Several dumpsters have collapsed and have been partially buried by sediments entering through the "blow hole". A large scoured depression occurs at the bow (southwest) end of the barge and proceeds partially around the starboard side. Deterioration of the barge has been minimal.

FH-6: FH-6 consists of three Liberty ship hulls and a barge. Two of the ship hulls are broken apart (approximately in half), making a total of six separate targets at FH-6. Each Liberty ship hull measured 476' long, 56' wide, and 15' high. The barge is a hopper type measuring 195' long, 35' wide, and 12' high.

Target A (Figure 7) is an intact Liberty ship hull which lies in a scoured hole at approximately 80 feet. Surrounding water depth is approximately 65 feet. The stern of hull A orients towards the north at approximately 360°. The stern of A is flush with the surrounding bottom. As one proceeds south towards the bow, a large hole develops encompassing the hull. Near midship a space of about twenty feet separates the sides of the ship hull from the sides of the scoured hole. The top edge of the ship hull is even or at some points slightly below the surrounding bottom. Near the bow end, the space separating the hull from the scoured hole narrows and disappears. The bow end rises approximately four feet above the surrounding bottom. Measurements (Table 2) indicate that, within the depression, the ship hull is not in danger of oversedimentation. Maximum clearance above target A is approximately 65 feet.

Since target B is one of the ship hulls that has been broken apart and separated, the two pieces are designated B1 and B2. Target B1 lies alongside the western side of target A. The scoured hole which encompasses target A also encompasses target B1.

B1 is the aft half of the ship hull and is adjacent to the A hull, orienting towards the north at approximately 10°. The stern of B1 is located on the western (starboard) side of hull A approximately one-third of the way aft of the bow (southern) end of A. Hurricane Frederick (1979), which broke the B hull apart and moved B1 into A, did so with enough force to buckle the side of A and the stern of B1 at the point of impact. A fair amount of sediments have washed into the southern (break) end of B1, but the hull is in no danger of oversedimentation based on the measurements (Table 2). There has been some deterioration of materials. Firebrick boilers have collapsed in both A and B1. Bulkheads have collapsed in all hulls. Several shrimp trawls have become entangled on the complex.

Target B2 lies approximately 230 feet to the southwest of target A (Figure 7). Measurements (Table 2) indicate a minimum clearance over the ship hull of approximately 53 feet. B2 is the forward section of the ship hull. The bow orients towards the south-southwest at approximately 210°. Like the A-B1 complex, B2 also lies in the scoured hole near its north (break) end. The bow is in a depression about four feet below the surrounding bottom. A large group of automobile tire units originally attached to the hull, occurs in the space separating the ship hull and the sides of the scoured hole on the starboard side aft of the bow. Deterioration of materials has been minimal.

Target C is a Liberty ship originally measuring 476' long, 56' wide, and 15' high, which has broken in almost identical halves and separated, creating two distinct targets designated C1 and C2 (Figure 7). C1 is separated from C2 by approximately 200-250 feet. Both C targets lie in approximately 65 feet of water. Minimum clearance above C1 and C2 is approximately 50 feet as derived from measurements (Table 2).

C1 is the forward section with the bow orienting towards the east at approximately 90°. There has been minimal deterioration of materials. Scouring is minimal except at the "break" end where a medium sized hole exists which is approximately 60' wide, 20' long, and 5' deep. A narrow, scoured trench occurs along the northern side of C1.

C2 is the aft half with the stern orienting to the northwest at approximately 310°. There has been some deterioration of C2. Besides "flaking", the firebrick boilers have collapsed as has a bulkhead just forward of the firebrick boilers. A depression similar to the one at C1 occurs at the "break" end of C2. A similar trench along the northern edge occurs also. Several shrimp trawls have become entangled on the C2 hull.

Barge D is a hopper barge measuring 195' long, 35' wide, and 12' high. The bow of barge D orients to the north at approximately 360°, lying upright and resting alongside and partially on top of the western (starboard) edge of the A hull. The starboard stern of barge D rests on top of the intersection of the B1 stern and the A hull. The port half of barge D rests even with the bottom surrounding the hole which encompasses the A-B1 complex. There has been minimal deterioration of barge D. A large "blow hole" exists at the port bow.

SIDE SCAN SONAR SURVEY

The area around each artificial reef was initially surveyed with a 200- to 300-m side scan sweep range in order to locate targets. After the targets were located, the sweep range was lowered to 75- or 100-m to obtain detailed records. The 100-m sweep range proved to be of maximum utility for record analysis. Table 1 lists the LORAN-C coordinates for each target within the limits of navigational accuracy.

FH-1: FH-1 consists of three side scan targets. According to measurements derived from three side scan sonar passes, target A (Figure 8), which appears to be a barge, averages about 190 feet long, about 70 feet wide, and 10 feet high. Scour marks about 20 feet wide are detectable around the southeast and southwest corners of the target. These scour marks, plus the 10-foot measured relief (Table 2), suggest that target A is not settling into the bottom.

Average calculated length of target B (Figure 9), which was determined to be a barge, was 162 feet, while average measured width was 34 feet. Relief measurements were unsatisfactory due to unidentified obstructions near the target which created secondary returns from the shadow zone on the most favorable tracks. Six to 12 foot wide scour marks around the south end of target B suggests very little penetration into the bottom. A 10 to 12-foot wide shadow zone on top of the target suggests that the metal is deteriorating.

Target C (Figures 10 and 11) is a barge with some scattered materials to the east. On different passes, target C's measurement varied between 205 and 250 feet in length, 40 to 52 feet in width, and 4 to 8 feet in height. Three railroad boxcars, one measured as 50 feet in length, lie east and slightly north of the target. The closest boxcar is about 25 feet from target C. The target's measurement discrepancy is probably due to an inaccurate speed estimate.

FH-3: FH-3 contains two scrapped Liberty ship hulls which each appear to be over 400 feet in length (Figure 12). Precise measurement of ship hull lengths was not possible due to an under-estimate of the survey vessel speed. This distortion was noted when survey tracks parallel to the target ship hull's orientation were compared. Ships' widths averaged 60 feet, while their heights were poorly defined, appearing to be greater than 10 feet. The two hulls appear to be about 200 feet apart at the closest point (Figure 13).

FH-4: Analysis of the survey tracks at FH-4 indicate two targets, both apparently barges (Figure 14). Target A (larger barge) had an average length, calculated from four survey tracks, of 195 feet. Scour marks and the smaller barge are visible from survey tracks that passed east of the larger barge (Figure 15). Target B (smaller barge) is estimated at 110 feet in length and 35 feet in width. Relief of the two targets could not be determined because the shadow zones of both targets could not be separated.

An echo-sounder profile (Figure 16) of Target A shows maximum relief of about 8 feet. Depressions about a foot deep along either side of the target may be the result of current scour intensified by the settling of the target into the mud bottom.

FH-5: The single target at FH-5 (Figures 17 and 18) is a barge. The average measured length and width is 190 feet and 34 feet, respectively. Barge height is estimated at no greater than 7 feet. Apparent scouring occurs in a 10 to 12-foot wide band around the southwest side of the barge (Figure 18).

FH-6: FH-6 is composed of three ship hulls, two of which are broken in half and separated (Figure 19). The disposition of hulls at FH-6 is shown in Figure 20 with one of the broken hulls resting alongside the intact hull. The intact hull (Target A) is about 470 feet long, 65 feet wide, and less than 10 feet high. A broken piece of hull (B1), about 260 feet long, lies alongside the intact hull. A third fragment (B2 in Figure 20) lies about 150 feet south of the "A" hull. C1 and C2, which are halves of a Liberty ship hull, are oriented NW/SE. It is not possible to distinguish bow from stern on these passes.

DISCUSSION

As evidenced by the results, both methods of monitoring and assessment of reef materials can provide information useful for management purposes. The purpose of this discussion is to highlight the benefits and drawbacks of each method by examining time, number of people, cost, and equipment involved in conducting each survey method. Also highlighted will be the utility of the data derived from each method.

PERSONNEL

There are specific equipment and space requirements related to the use of side scan sonar; consequently, a boat of 35 feet in length or greater with a covered cabin is required. This usually requires the services of a captain and one crew member to run the boat. The complex nature of the side scan sonar equipment requires that a trained operator be available, as well as a log and time keeper who is familiar with the methodology. Since it is important to have a general idea where artificial reef materials are located, it may be necessary to include a person involved in the artificial reef program who is knowledgeable of the locations of materials. This person can also function as the crew member. Consequently, the side scan sonar survey method would require a minimum of four people.

The SCUBA survey method requires at least two properly trained SCUBA divers and one person to remain on the boat while the divers are submerged in order not to leave the boat untended. The size of the boat required is dependent primarily on the distance offshore that artificial reefs are located. The survey conducted for this study required the use of a boat at least 22 feet in length. Special captain or crew considerations were not required. Minimum personnel required for the SCUBA survey is three.

EQUIPMENT

Both methods of survey require the use of boats with offshore capabilities. The size of the boat used for the side scan sonar method is dictated by space requirements of the equipment and protection of the equipment from the elements. The side scan sonar unit requires either an on-board generator or several standard 12 volt marine batteries and a battery charger. Boat size for the SCUBA method is dictated primarily by distance from shore at which artificial reefs are located.

Both survey methods require chart-reading depth recorders and LORAN-C units. The side scan sonar method requires the use of side scan sonar equipment of sufficient resolution to provide accurate and precise images of survey targets. The SCUBA method requires at least two full sets of SCUBA equipment including masks, snorkels, fins, regulators, backpacks/ safety vests, and wetsuits. A minimum of four air tanks are needed if two dives per trip are expected.

COST

Costs for both survey methods will vary depending on the number of targets and the distance of the targets from shore and from each other. For this study, the side scan sonar method costs $8,911.00, while the SCUBA survey costs $3,100.00. Costs will also vary depending on the number of people employed and the size of the boat used to conduct the surveys.

TIME

The side scan sonar method required an estimated 146 man-hours and was accomplished primarily over a 36 to 48-hour period. The SCUBA method required 262 man-hours and required a period of approximately five months to accomplish. Analysis and write-up of data were not included in the time estimates.

DATA

As identified under the objective, there are four categories of data needs: a) LORAN-C coordinates for all materials, b) water depth and height of reef material above the bottom, c) composition and orientation of reef materials, and d) physical condition of materials regarding exposure, subsidence, and scattering. Other data needs may be specific to individual artificial reef programs.

LORAN-C Coordinates

Comparison of LORAN-C coordinates resulting from both survey methods indicates minimal differences. Because the technique used to record coordinates with the SCUBA method results in a direct measurement, it is probable that those coordinates are more precise than those recorded with the side scan sonar method, which were derived from the remote sensing data and must account for boat speed. From a management perspective, there is no difference in the utility of the data.

Water Depth/Height of Material Over Bottom

General water depth at each artificial reef site was recorded using a chart fathometer on both the side scan sonar and SCUBA survey methods. Though a chart fathometer can be used to estimate vertical height of artificial reef materials over the bottom, the technique was not used throughout this study. Separate cruise tracks would be required to acquire vertical height data using the chart fathometer and would increase the time and cost of the survey. Comparison of data found in Table 2 indicates significant differences in the two methods for collecting vertical height data. The technique employed during the SCUBA survey is a direct measurement and thus is more precise than the values estimated by remote sensing. Referring to Table 2, in most cases estimates of vertical height were not possible with the side scan sonar method either due to shadowing or an inadequate image. In those cases where an estimate was made, the height was recorded as either greater than or less than a certain value.

Composition and Orientation of Structures

When using side scan sonar equipment in this application, one can assume that the identity of the targets to be surveyed would be known. It is important; however, to point out that in most cases when side scan sonar is being used to locate a target, confirmation of the identity of such targets is made using SCUBA divers. Referring to Figure 11, for example, it is difficult to ascertain that targets A and B are railroad boxcars and that target C is a hopper barge which is lying bottom side up. Figure 20 is an image of three ship hulls. High sea conditions caused this image to deteriorate, thus it is difficult to determine the target identities; however, a clearer, more precise image would be much easier to analyze. Target B1 in Figure 20 is a barge lying alongside the ship hull (Target A). Identification of this target using side scan sonar alone would have been very difficult. Since SCUBA is a direct observation, in most cases with adequate water visibility identification of targets is precise.

Regarding orientation of artificial reef materials, comparison of Figures 2 through 7 and Figures 8 through 20 indicate some differences; however, from a management perspective there is no difference in the utility of the data.

Physical Condition of Materials

Exposure - Exposure of man-made materials, especially steel structures such as ship and barge hulls, results in deterioration over time due to water salinity and tidal surge. Data from the side scan sonar survey was inadequate to determine deterioration due to exposure except in isolated cases such as the conclusion drawn from analysis of side scan sonar data on FH-1 Target B. Shadow zone detection indicates that metal may have corroded and collapsed inward. Observations from an earlier study (Lukens and Cirino, 1985) confirm that conclusion. It is important to note, however, that deterioration of most of the five Liberty ship hulls surveyed is extant in the form of collapsed bulkheads and large structural cracks in the hulls. These were observed by the SCUBA divers but not detected with the side scan sonar equipment.

Subsidence - Any time a large structure rests on a mud/silt/sand bottom, a certain amount of initial subsidence into that relatively soft bottom occurs. Depending on the weight and displacement of the structure, the composition of the bottom sediments, and the prevailing tidal action (or occasional storm surge), the degree of subsidence of a structure into the bottom varies. It is difficult to determine from one measurement whether or not a ship or barge hull is subsiding; however, the ability to obtain precise measurements over time will allow an artificial reef manager to ascertain the degree of subsidence if any. In the above discussion of measurements of vertical height of materials above the bottom, it is evident that reliance on side scan sonar surveys to detect subsidence may not be warranted. The capability of the side scan sonar equipment to detect scouring is valuable in determining some of the effects of tidal and storm surge; however, precision is lacking. For instance, it was observed by the SCUBA divers that target A at FH-6 is an intact Liberty ship hull which lies in a depression in the bottom which encompasses the entire hull. There is no vertical height of the ship hull above the bottom profile, yet this phenomenon was undetectable from the side scan sonar tracks (Figure 20, Target A). Since the measuring technique used in the SCUBA survey results in direct measurements, precise records of the degree of subsidence, if any, can be acquired.

Scattering - Heavy tidal and storm surge can result in movement and scattering of artificial reef materials. During the 1970's the use of automobile tires was commonplace. In many cases tidal and storm surge resulted in extensive scattering of tires. This has resulted in tighter guidelines on the use of tires in high-energy situations (Stone, 1985). Both the side scan sonar and SCUBA surveys are equally adequate in documenting the position of materials. Subsequent surveys of the same artificial reef sites should provide clear indications of the movement of any materials. It is clear that separation and scattering of two ship hulls has occurred (Figure 20).

CONCLUSIONS

Artificial reef administrative and support programs and the reefs they create vary in many ways, with the more prominent differences being on-site environmental conditions, distance offshore, administrative structures, funding bases, and goals and objectives particular to individual programs. Though monitoring and assessment of materials used by the various artificial reef programs is an important management function across all program types, such a monitoring and assessment initiative may be accomplished in various ways depending on the factors mentioned above.

The objective of this study is to demonstrate the capabilities and limitations of survey methods using SCUBA and side scan sonar to measure important physical parameters of artificial reef materials. Table 3 provides a comparison of the relative utility of the data resulting from both methods. Analysis of Table 3 would seem to indicate that the SCUBA method is a better method to use to obtain these data; however, other factors must be considered before making that decision.

Some artificial reef programs may not require data from all categories listed in Table 3. The degree of precision required for adequate management of an artificial reef program may vary due to environmental factors; the proximity of artificial reef materials to shipping lanes, coral reefs, etc.; or funding constraints. No clear-cut decision can be made as to the best methodology for a particular artificial reef program until the goals, objectives and idiosyncracies of that program are analyzed. It is clear that both methods presented here offer useful data and that each method fulfills some needs better than the other. The potential of the side scan sonar survey method is greater if more expensive, higher resolution equipment is used; however, at present the cost would far outweigh the benefits. As this technology becomes more refined, it may prove to be more cost effective, efficient and precise than other methods. Certainly in water depths which exceed the safe diving range for SCUBA, the side scan sonar method should be used.

Table 3. Comparison of the SCUBA and Side Scan Sonar Survey Methods Regarding the Utility of the Resultant Data for LORAN-C Coordinates, Vertical Profile, Composition, Orientation, Effects of Exposure, Subsidence, and Scattering of Materials.

DATA	SIDE SCAN SONAR	SCUBA
LORAN-C Coordinates	No Significant Difference	No Significant Difference
Vertical Profile	Not Precise	Precise
Composition	Not Precise	Precise
Orientation	No Significant Difference	No Significant Difference
Effects of Exposure	Not Precise	Precise
Subsidence	Not Precise	Precise
Scattering	Precise, Efficient	Precise, Less Efficient

When artificial (man-made) materials are deployed to construct a reef, the permit holder, whether it be a local or private group or a government agency, has a responsibility to see that the artificial reef does not negatively impact other interests, such as shipping and commercial fishing. In cases where tax dollars are used to support reef construction activities, permit holders have a responsibility to see that the tax money is wisely spent in a responsible and scientifically sound manner. Guidance from the National Artificial Reef Plan developed by Stone (1985) clearly outlines the need for compliance and performance monitoring of all artificial reefs. This report is designed to outline the benefits and drawbacks of two methods of monitoring and assessment of artificial reef materials. Many cases will call for the use of the side scan sonar method; however, when a high degree of precision is required, a manager may opt to use the SCUBA method. The most comprehensive monitoring and assessment effort would include both methods, applied when the specific method is best suited for the available dollars and the data needed.

LORAN-C COORDINATES

Regardless of the idiosyncracies of any particular artificial reef program, LORAN-C coordinates, or some equally reliable positioning mechanism, are vital. The choice of how to acquire those coordinates depends on the degree of accuracy required, the amount of money available, and the availability of human resources to the program. From a management perspective, data resulting from both survey methods addressed in this report are generally sufficient to meet management needs.

WATER DEPTH AND HEIGHT OF MATERIALS OVER BOTTOM

As stated in the justification section, water depth and clearance above reef materials is an important information area due to navigation requirements. The degree of accuracy and precision may depend on the proximity of artificial reefs to navigation fairways or the amount of vessel traffic in the area. If a great deal of precision is required, the use of a high quality chart fathometer or the technique outlined in the SCUBA survey method should be used. Reliance on side scan sonar for detail precision may be impractical.

COMPOSITION AND ORIENTATION OF STRUCTURES

As pointed out above, it may be difficult in most cases to accurately identify artificial reef materials encountered by side scan sonar if the composition of the reef is not already known. If positive identification is required, the probability of success would be much higher using the SCUBA survey method. Specific cases, such as boats or aircraft which have a readily identifiable shape, may lend themselves to the use of side scan sonar; however, even in those cases, accurate identification using side scan sonar may depend upon the position of the object on the bottom or its proximity to another structure.

Determination of the orientation of materials within a given reef site can be acquired with either method without a loss of the utility of the data; however, since the SCUBA method is a direct measurement, it has higher precision associated with it. Choice of specific methodology would depend on the degree of precision desired, available funds and other resources (i.e. SCUBA divers).

PHYSICAL CONDITION OF MATERIALS

The physical condition of artificial reef materials has important implications for reef managers for a number of reasons. It is very expensive to deploy such materials as ship hulls and barges, particularly if the reef site is very far offshore (Gusa, Personal Communication 1989). If deterioration of materials is rapid it can affect the effectiveness of a reef in attracting and holding fish populations and developing habitat. It also requires replenishment of reef materials, which again is costly.

Both survey methods can yield equally useful information in regards to scattering of materials due to tidal and storm surge or other outside influence. Due to its capability of searching large areas in a relatively short time the side scan sonar method has a particular advantage in locating material which has moved off-site. Searches using a chart fathometer are much more intensive. Choice of methodology would depend upon available time and funding.

Subsidence of materials into bottom sediments is a problem which may not plague all reef programs, but it is a particular problem in areas where soft bottom sediments occur and where tidal and storm surge is high in energy. If a reef site is prone to subsidence it can reduce the effectiveness of a high-profile reef. The degree of precision required related to data on subsidence will be reef site specific and will vary from program to program. The technique used in the SCUBA method is designed to provide a high degree of precision. Lukens and Cirino (1985) devised the technique to be applied off Mississippi where bottom sediments are comprised primarily of silty mud. The technique is also particularly suited to materials such as ship hulls and barges. Materials such as piles of concrete rubble may not be well suited to the technique. As a result of the Lukens and Cirino (1985) study, a Subsidence Index was developed to help reef managers keep track of subsidence. Refer to Appendix 2 for a full discussion of that index.

One of the major artificial reef issues as yet to be resolved is the issue of liability in the case of injury, death, or loss of property (i.e. fishing nets). A ship hull, for instance, in a state of severe deterioration could be dangerous to recreational SCUBA divers. Records describing the condition of materials may be useful in litigation. In the example of a rapidly deteriorating reef site, notices could be placed in newspapers, dive shops or other outlets warning recreational SCUBA divers that specific areas are dangerous. Reliance on side scan sonar may provide some limited information regarding the condition of materials, but greater precision will result from actual observations by SCUBA divers.

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APPENDIX 1

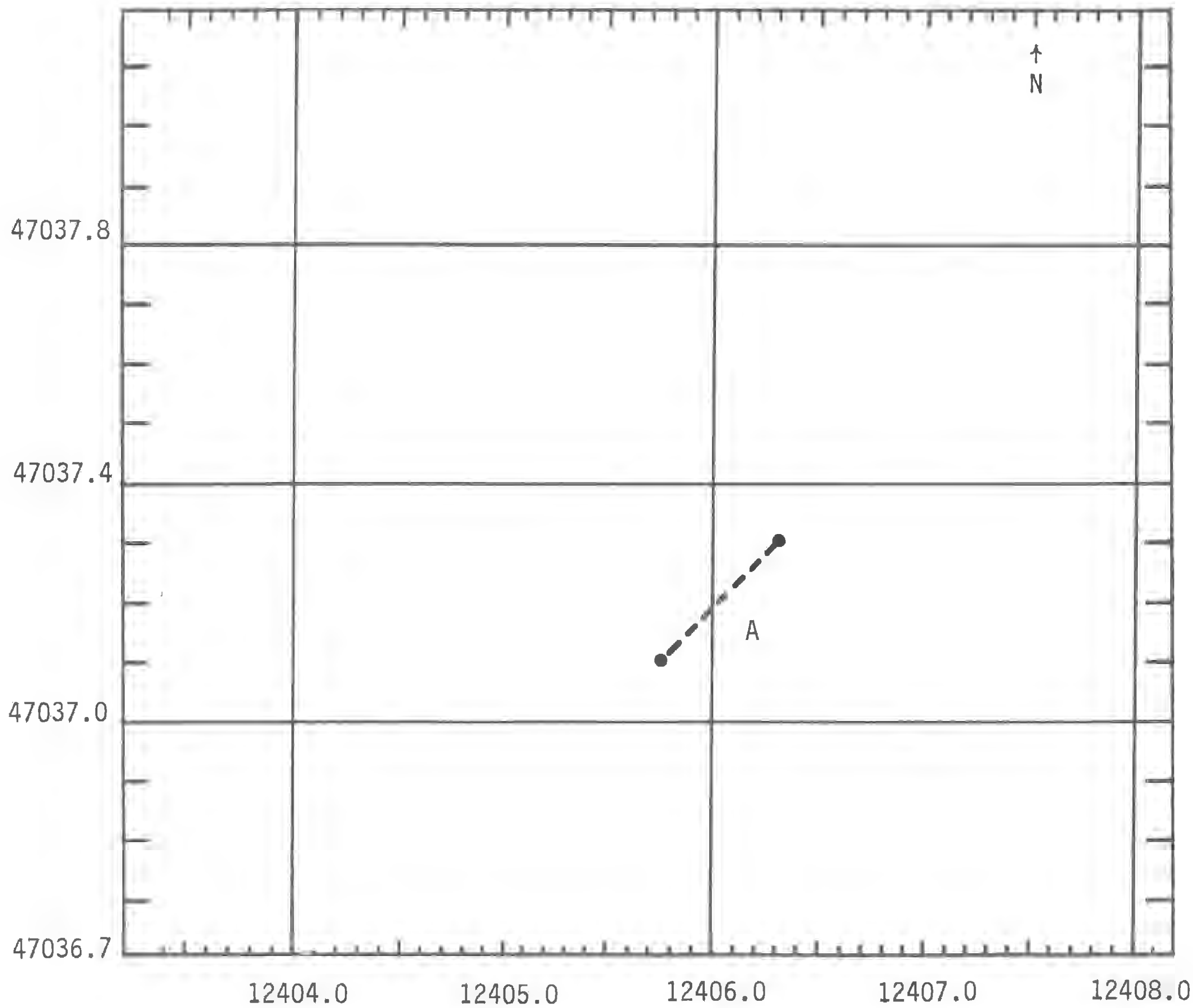

Figure 2. Target A is a barge at site FH-1, plotted using data from the SCUBA survey method.

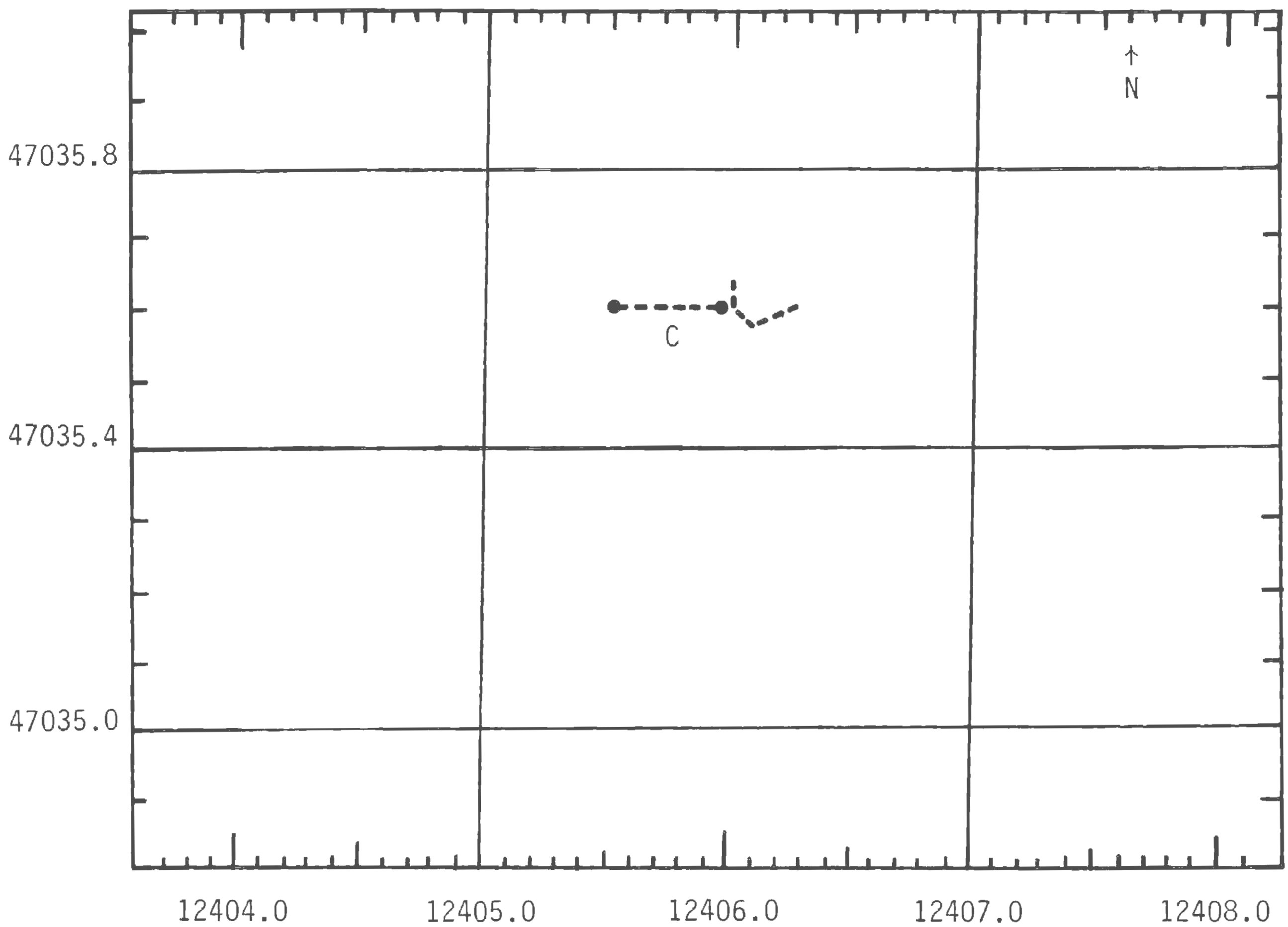

Figure 3. Target C is a barge at site FH-1, plotted using data from the SCUBA survey method. Materials to the right of the barge are three railroad box cars.

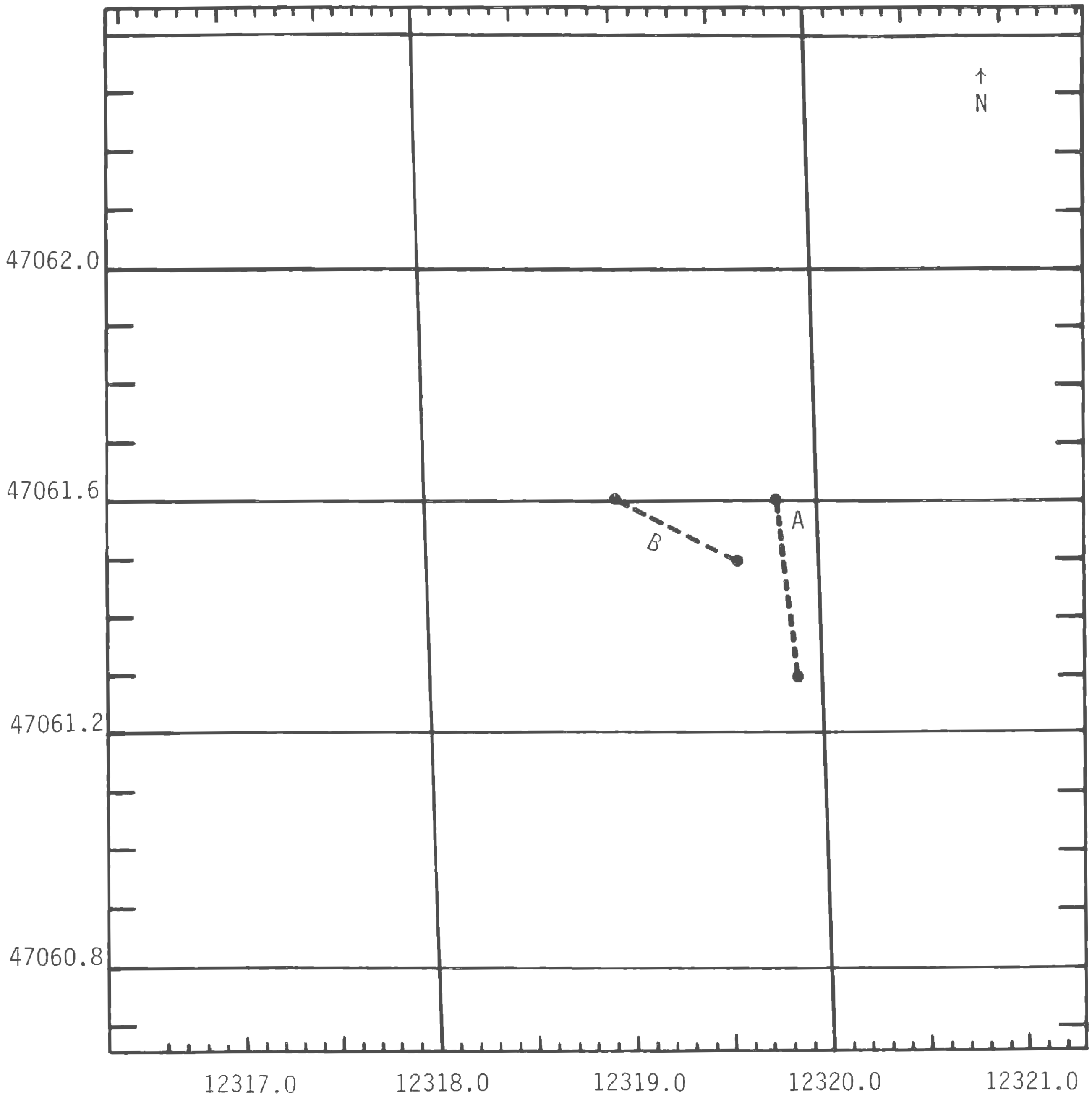

Figure 4. Targets A and B are Liberty ship hulls at site FH-3, plotted using data from the SCUBA survey method.

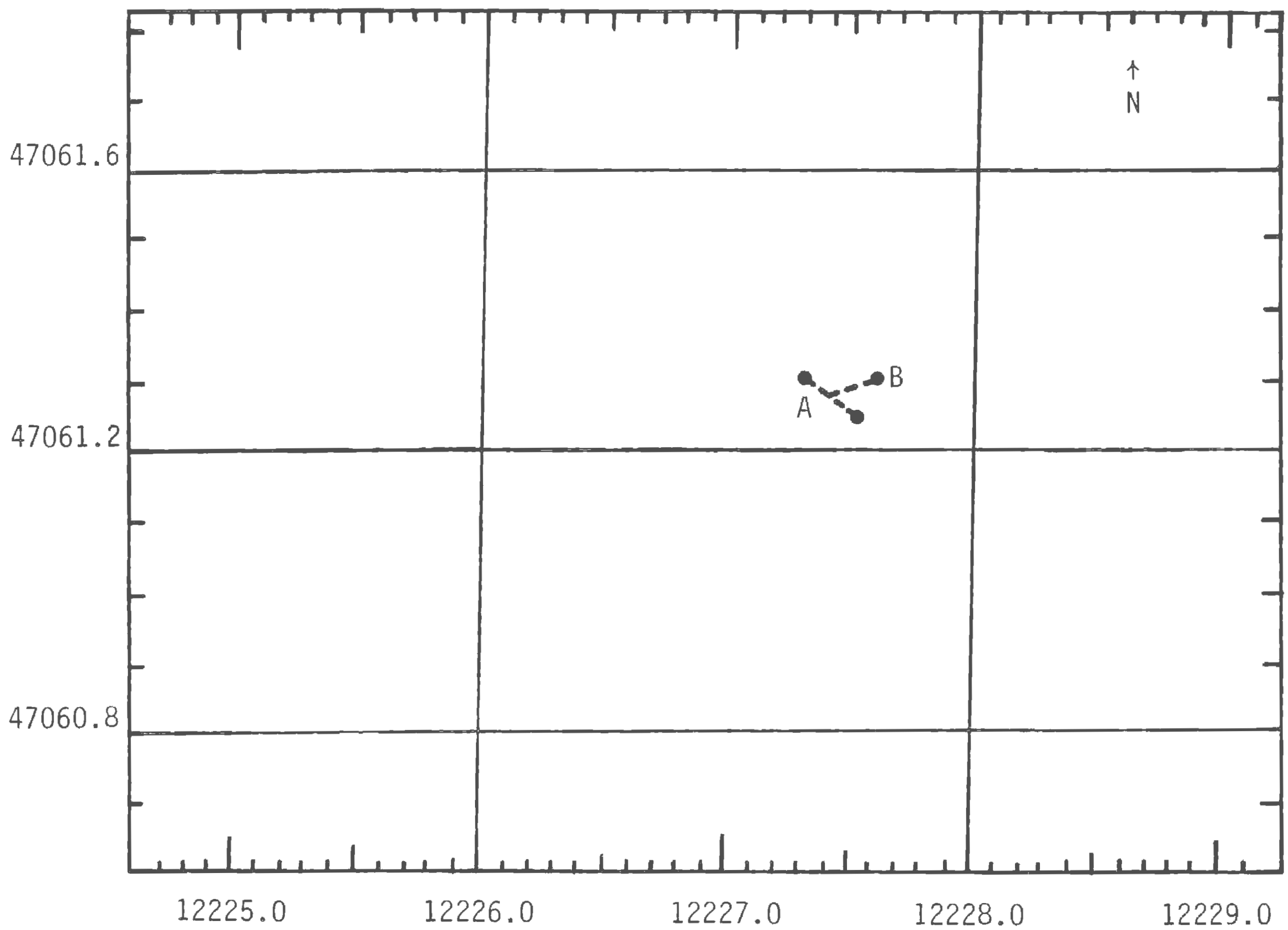

Figure 5. Targets A and B are barges at site FH-4, plotted using data from the SCUBA survey method.

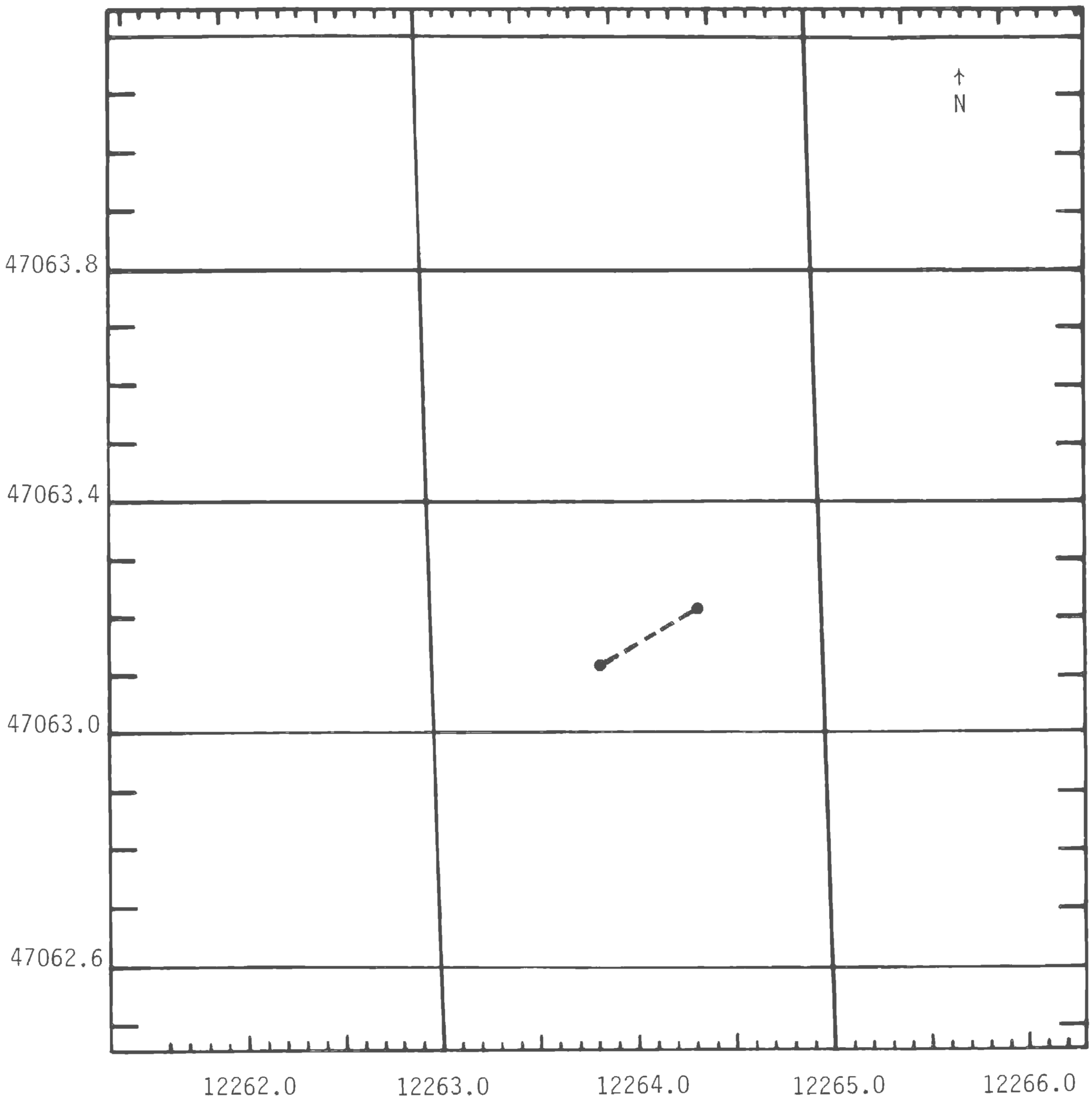

Figure 6. Target is a barge at site FH-5, plotted using the SCUBA survey method.

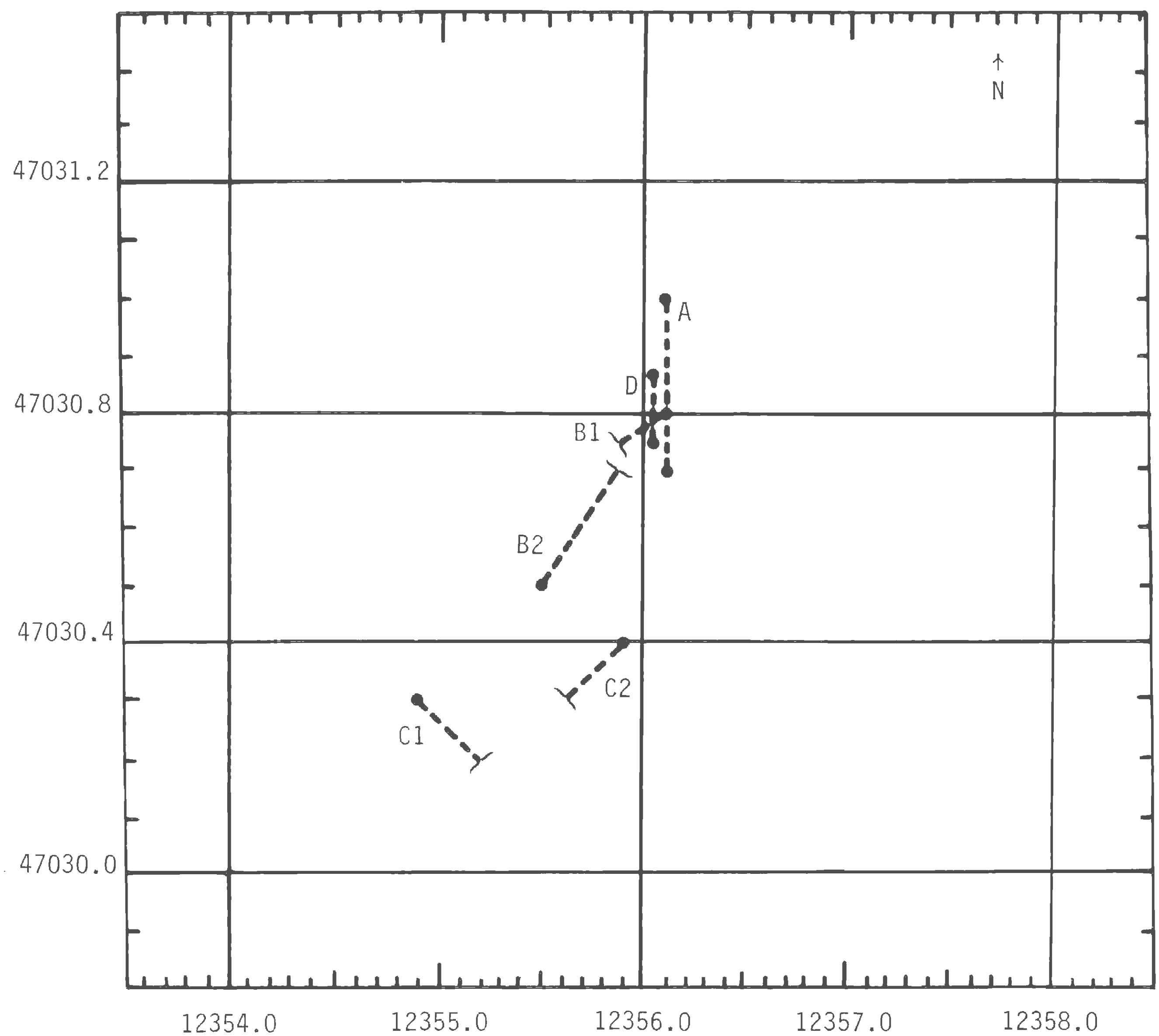

Figure 7. Target A is an intact Liberty ship hull. Targets B1, B2, C1, and C2 are each halves of Liberty ship hulls, and Target D is a barge. All targets were plotted using the SCUBA survey method.

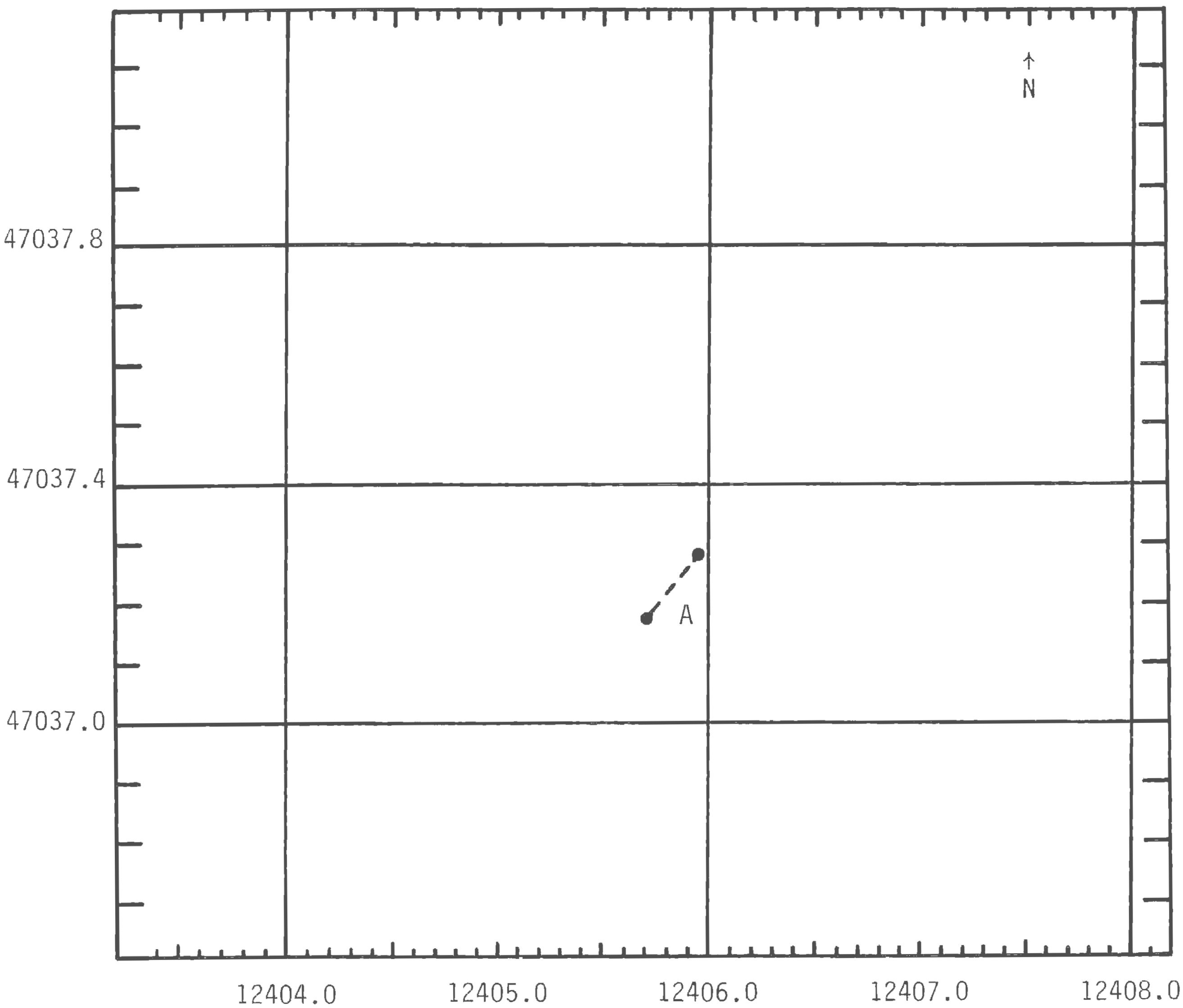

Figure 8. Target A is a barge at site FH-1, plotted using data from the side scan sonar survey method.

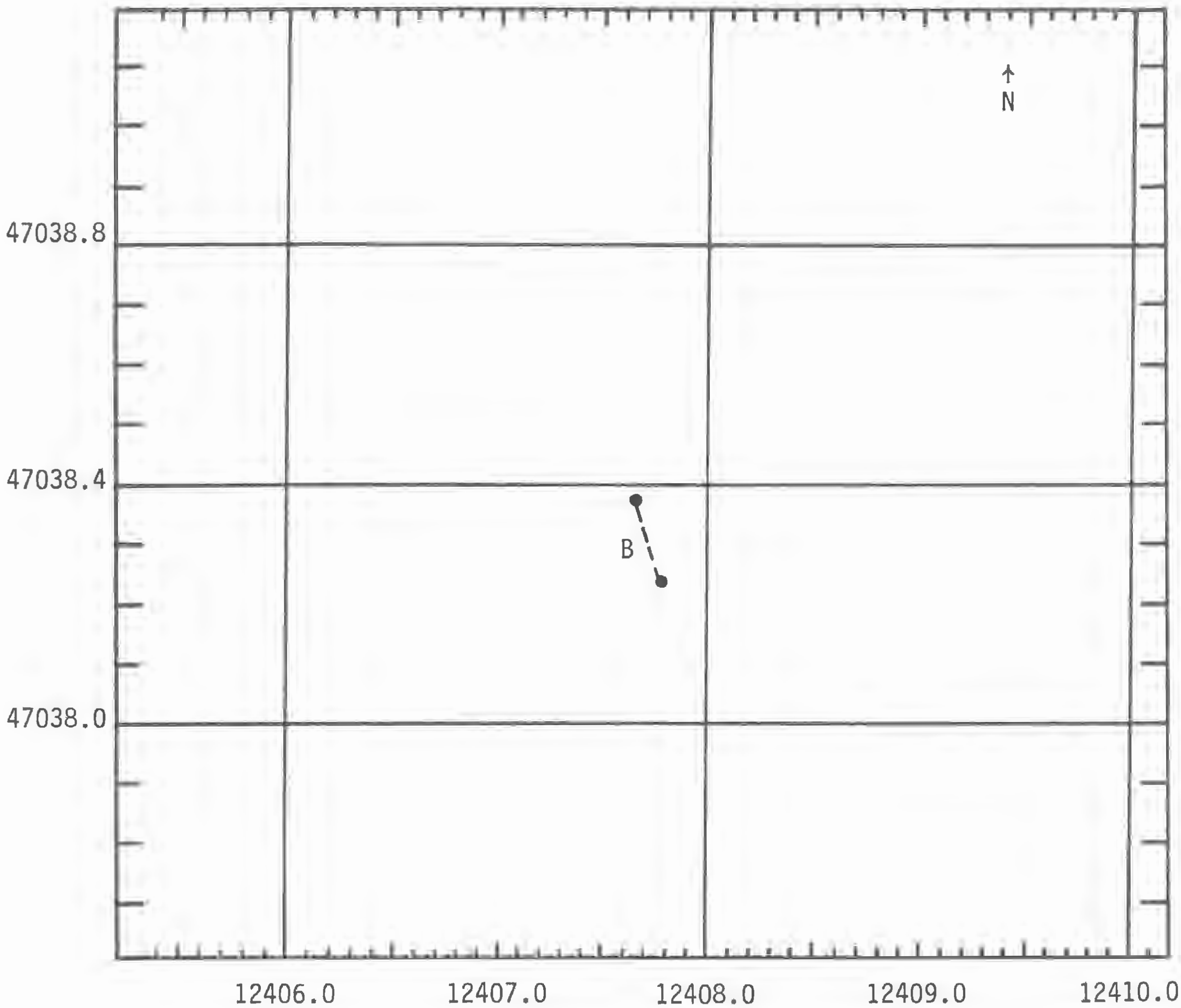

Figure 9. Target B is a barge at site FH-1, plotted using data from the side scan sonar survey method.

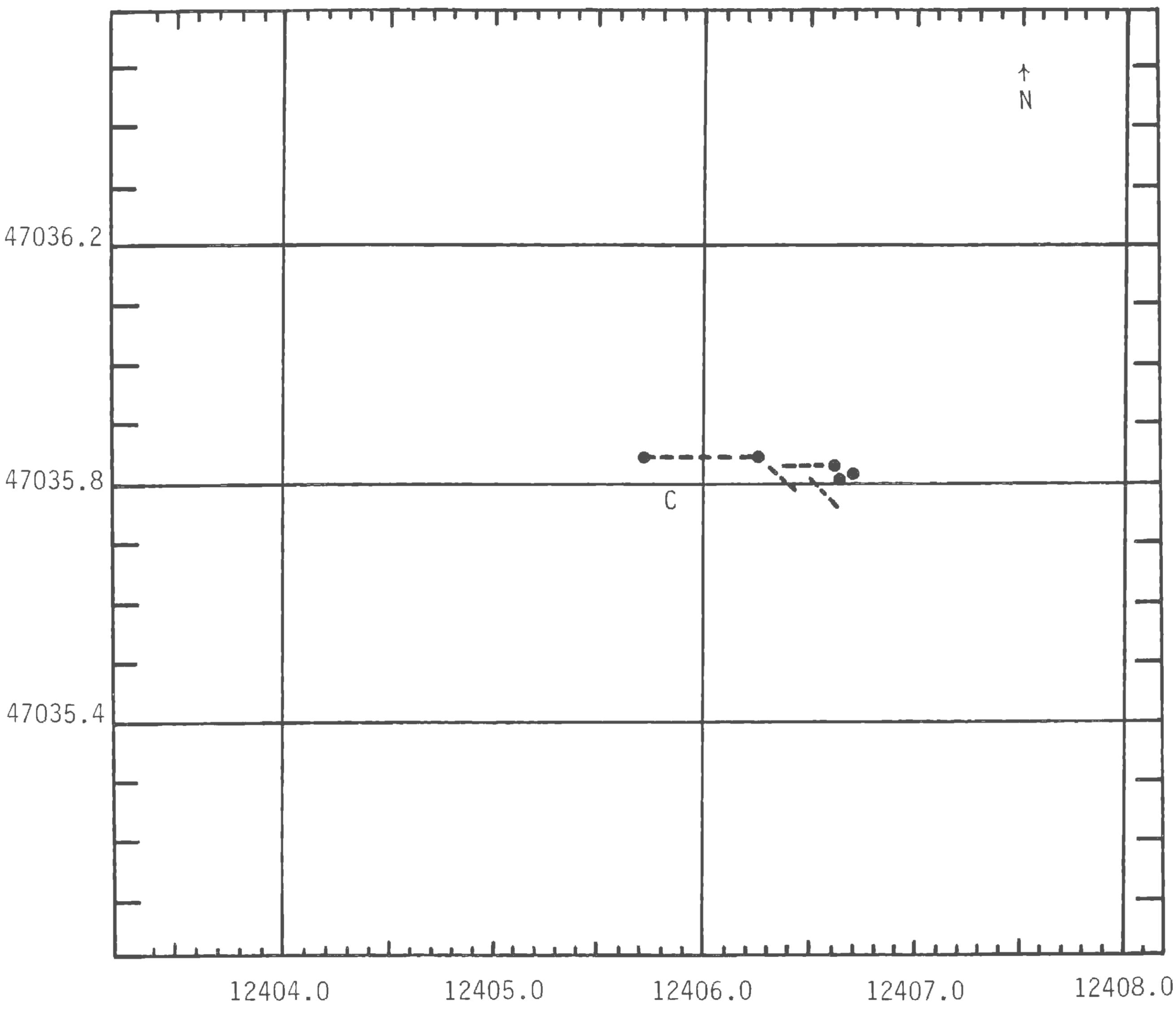

Figure 10. Target C is a barge. Material to the right of Target C was unidentifiable from the side scan sonar record. All material were plotted using data from the side scan sonar survey method.

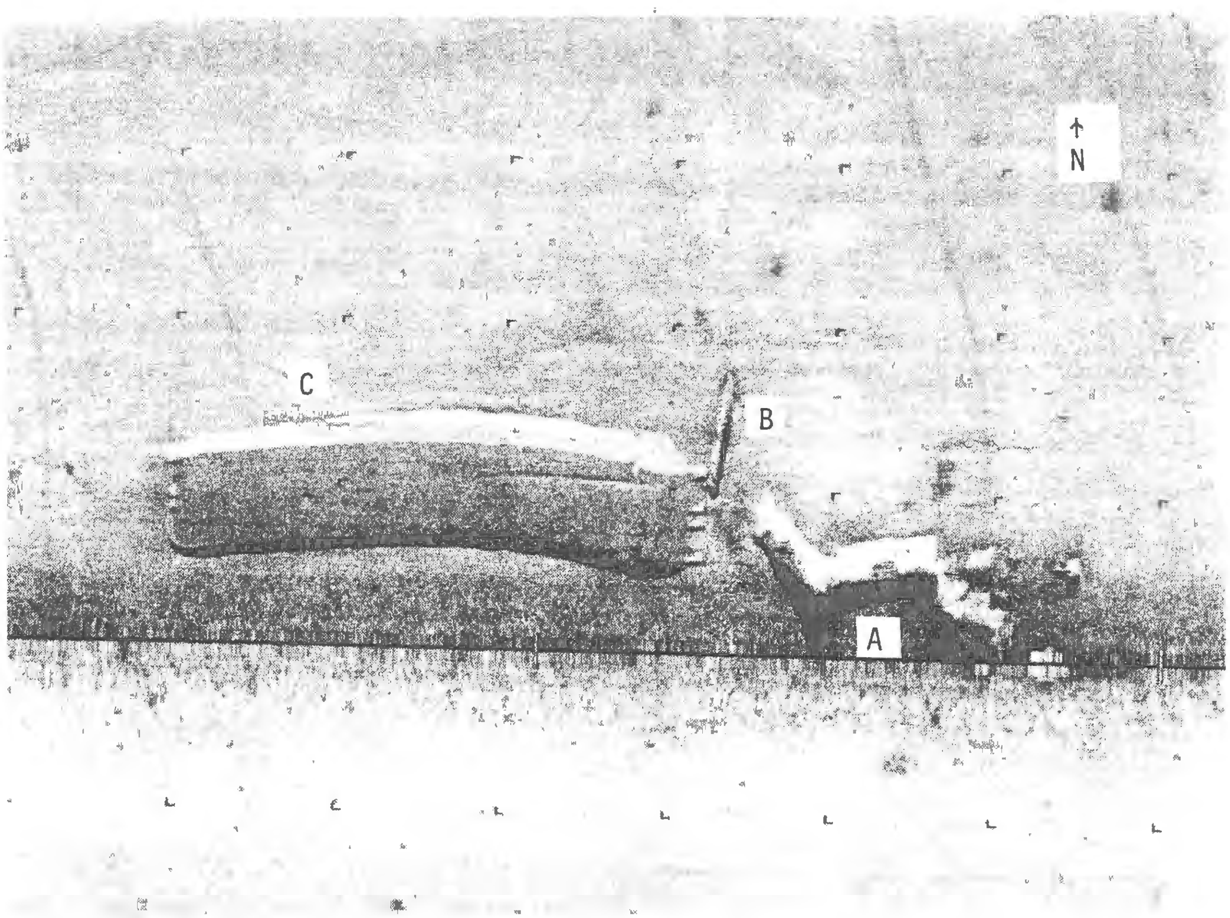

Figure 11. Reef target disposition using side scan sonar at site FH-1. Targets A and B are unknown, while Target C is a barge. Scale along-track is 10.7 m/cm. Scale across-track is 10 m/cm.

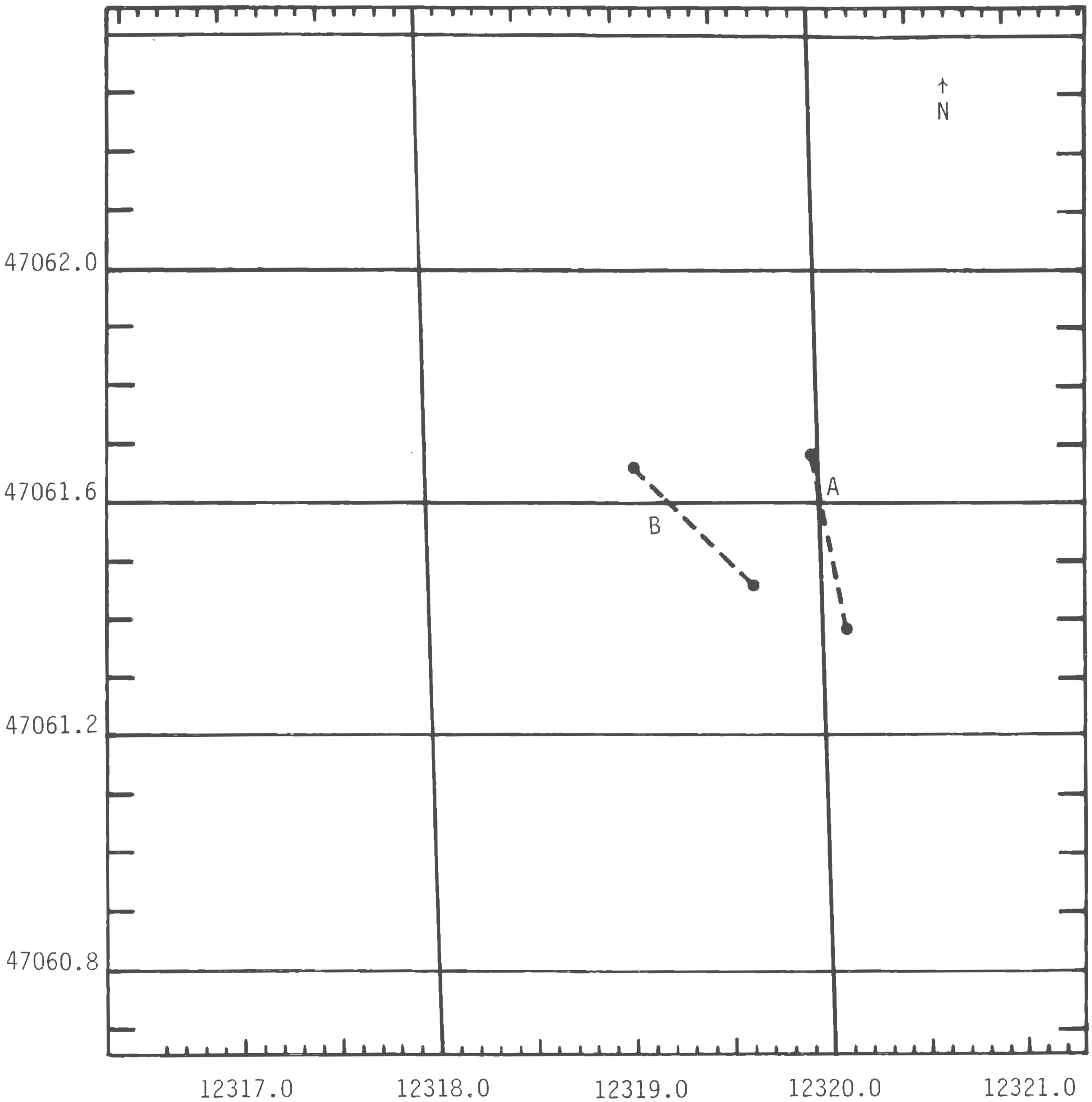

Figure 12. Targets A and B are Liberty ship hulls, plotted using data from the side scan sonar survey method.

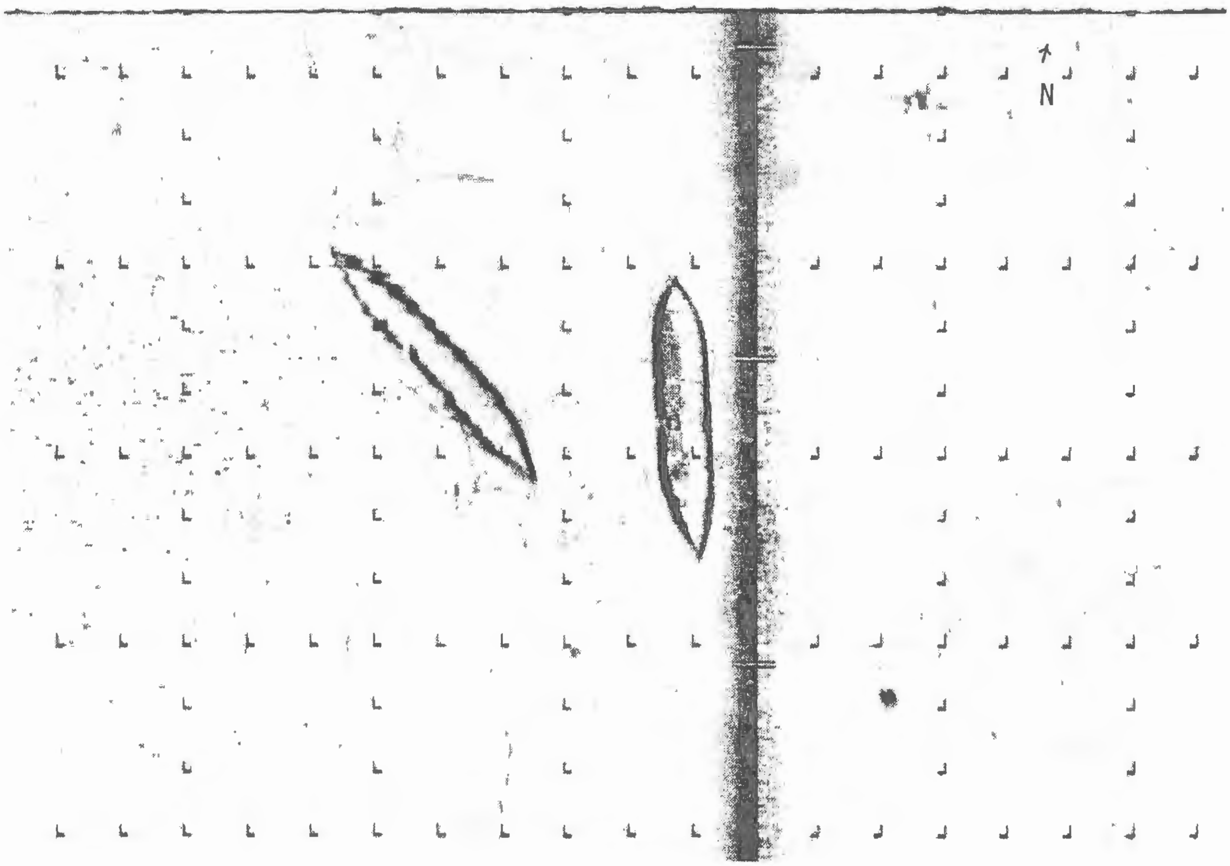

Figure 13. Liberty ship hulls from side scan sonar record at site FH-3. Scale along-track is 32 m/cm and across-track is 30 m/cm.

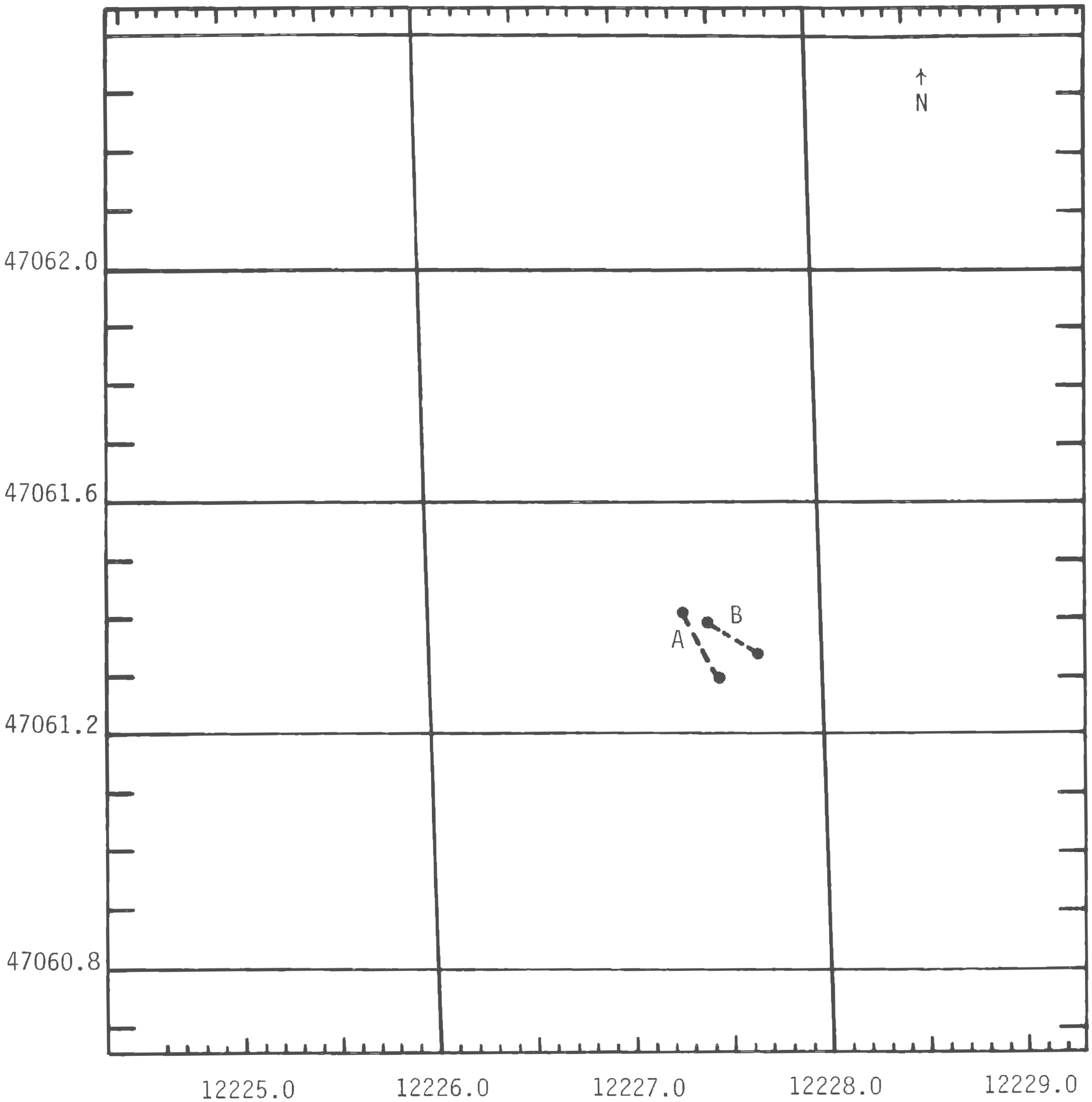

Figure 14. Targets A and B are barges at site FH-4, plotted using data from side scan sonar survey method.

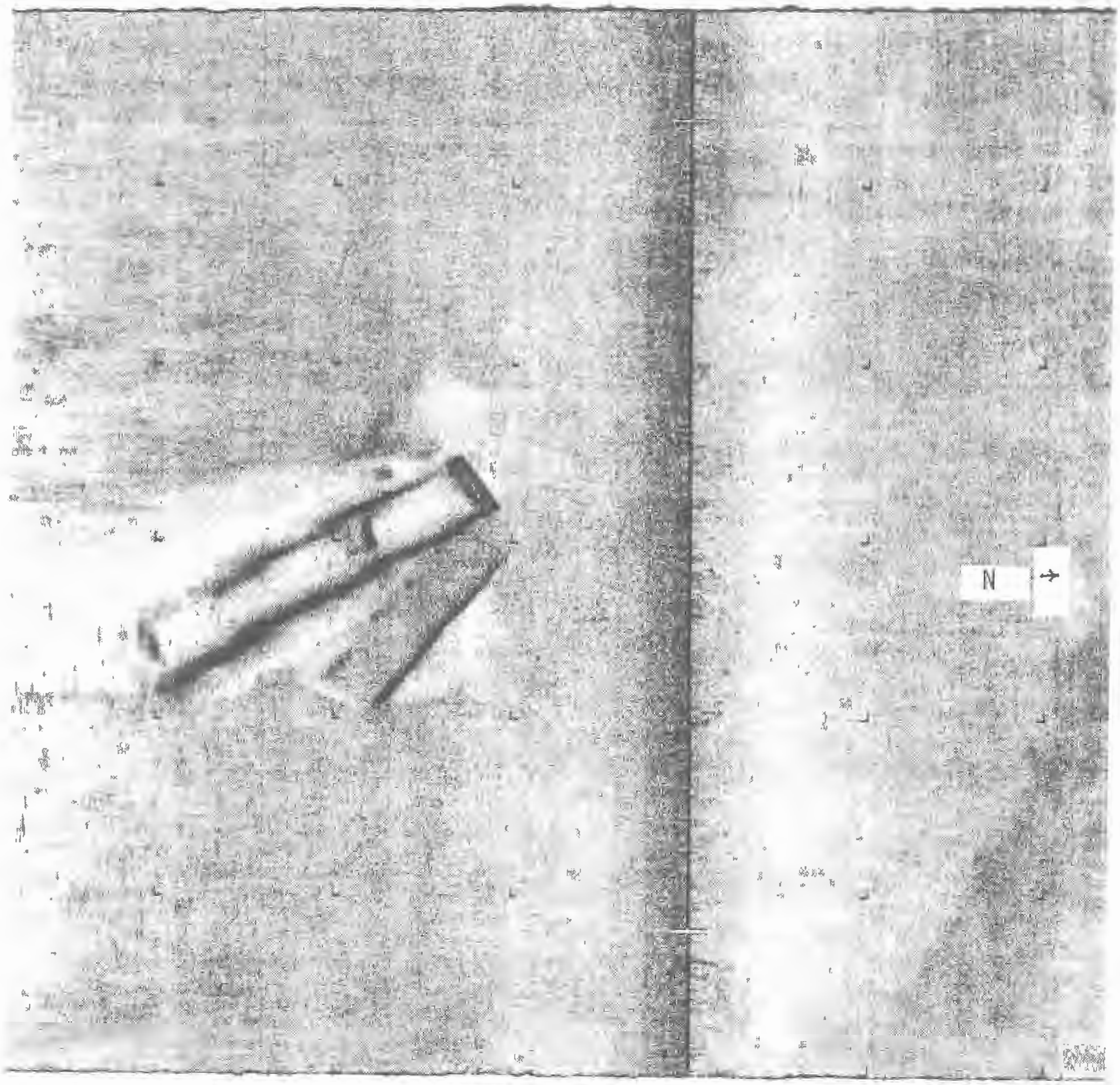

Figure 15. Two barges from side scan sonar record at FH-4. Scouring is indicated by light areas to the right of the smaller barge and above the larger barge. Scale along-track is 10 m/cm and across-track is 10.7 m/cm.

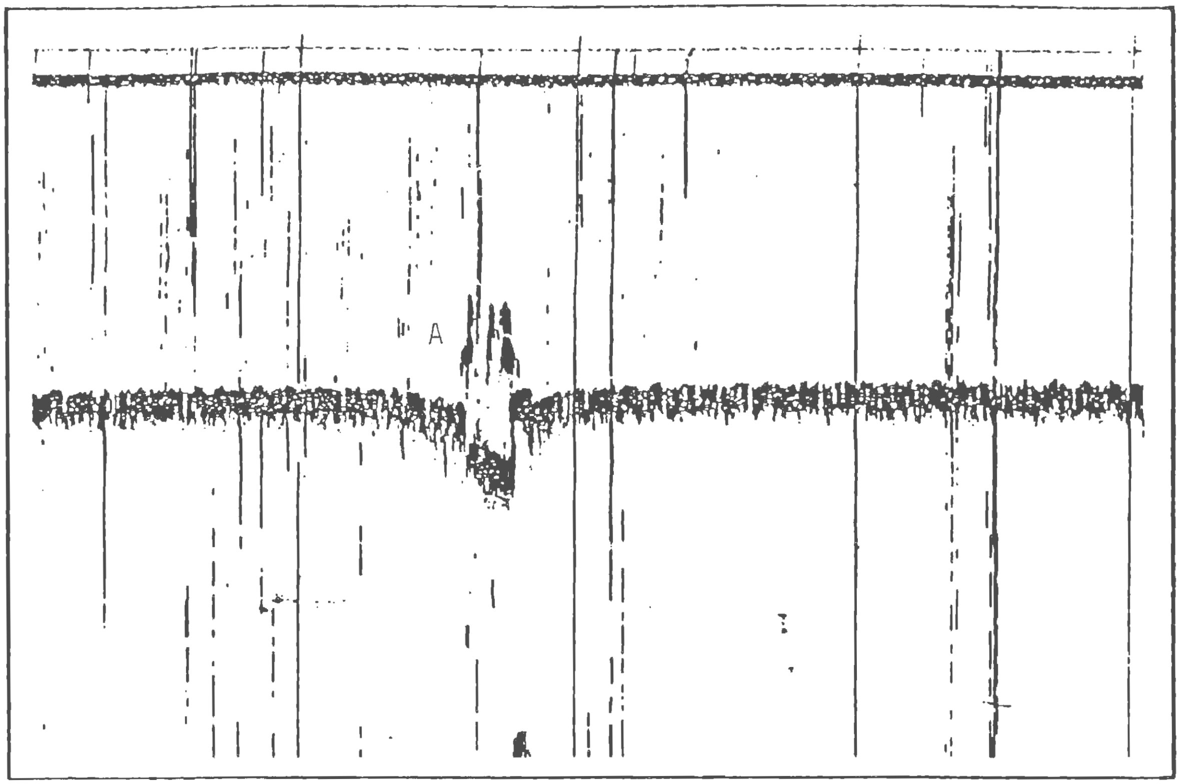

Figure 16. A depth recorder profile of Target A (barge) at FH-4. According to this profile one to two feet of scouring has occurred along both sides of the barge. The barge appears to have settled about five feet into the substrate.

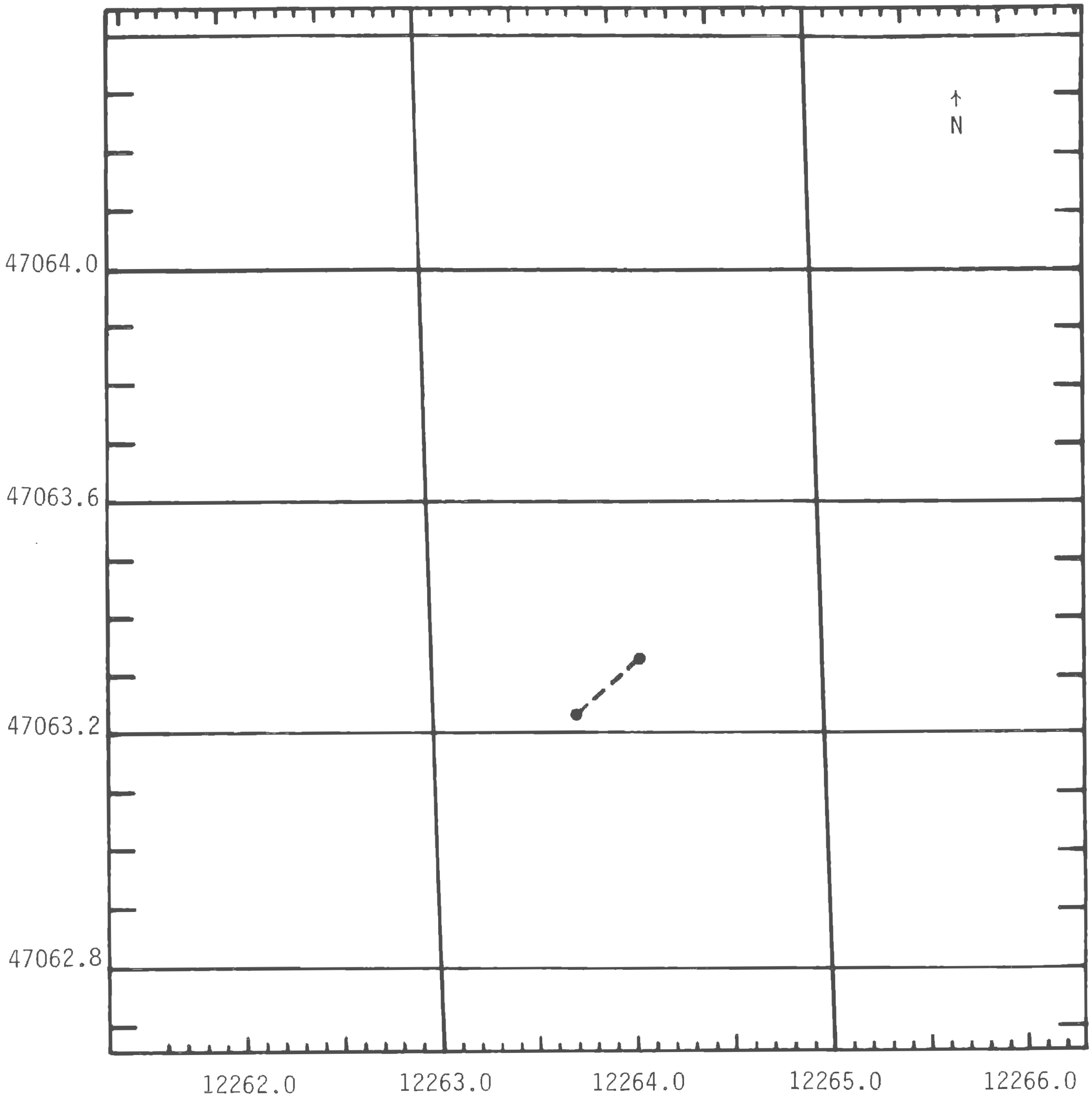

Figure 17. Target is a barge at site FH-5, plotted using data from the side scan sonar survey method.

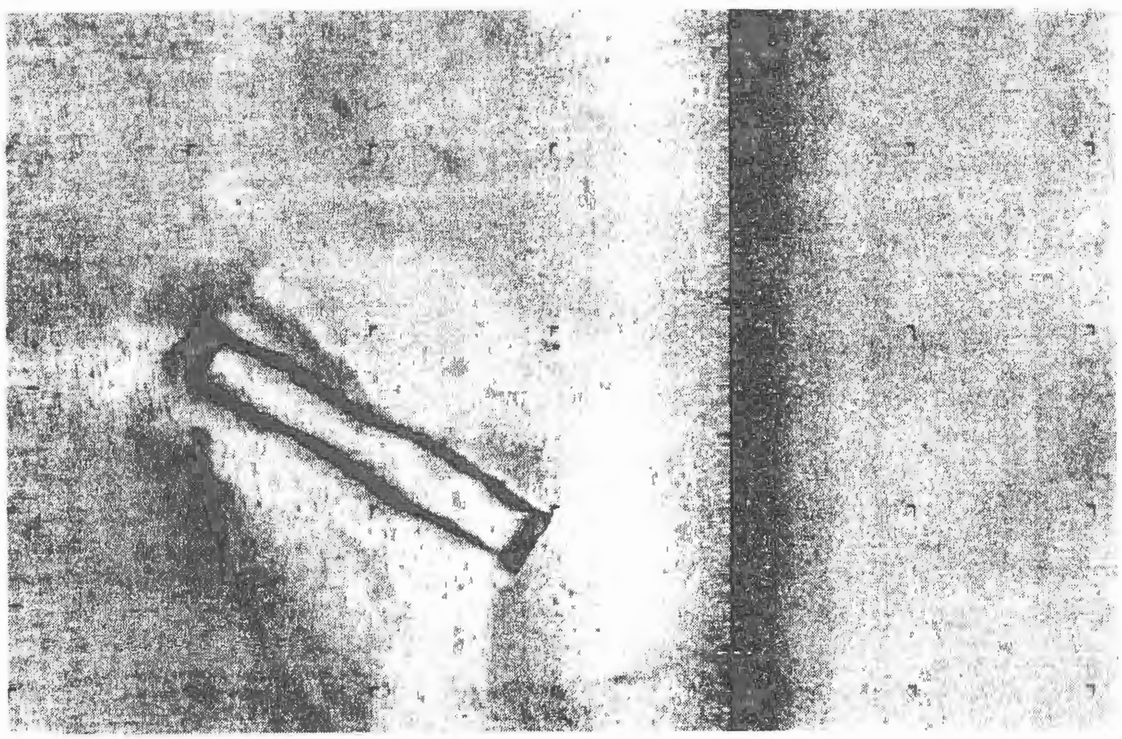

Figure 18. Barge from side scan sonar record at FH-5. The large white areas above and to the right of the barge indicate scouring and possibly some settling into the substrate.

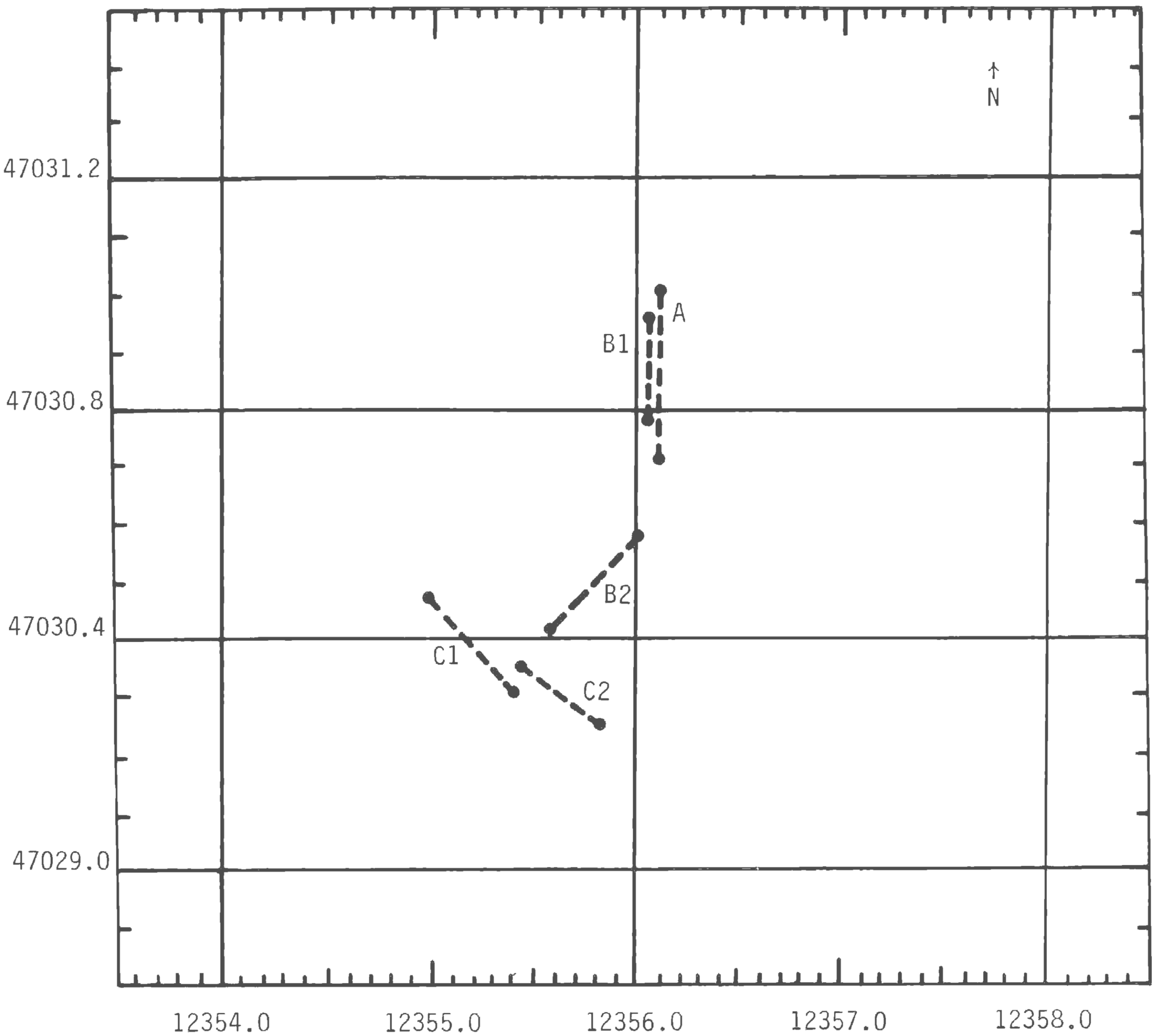

Figure 19. Target A is an intact Liberty ship hull. Target B1 is a barge which was misidentified as half of a Liberty ship hull. Targets B2, C1, and C2 are halves of Liberty ship hulls. All materials were plotted at site FH-6 using data from the side scan sonar survey method.

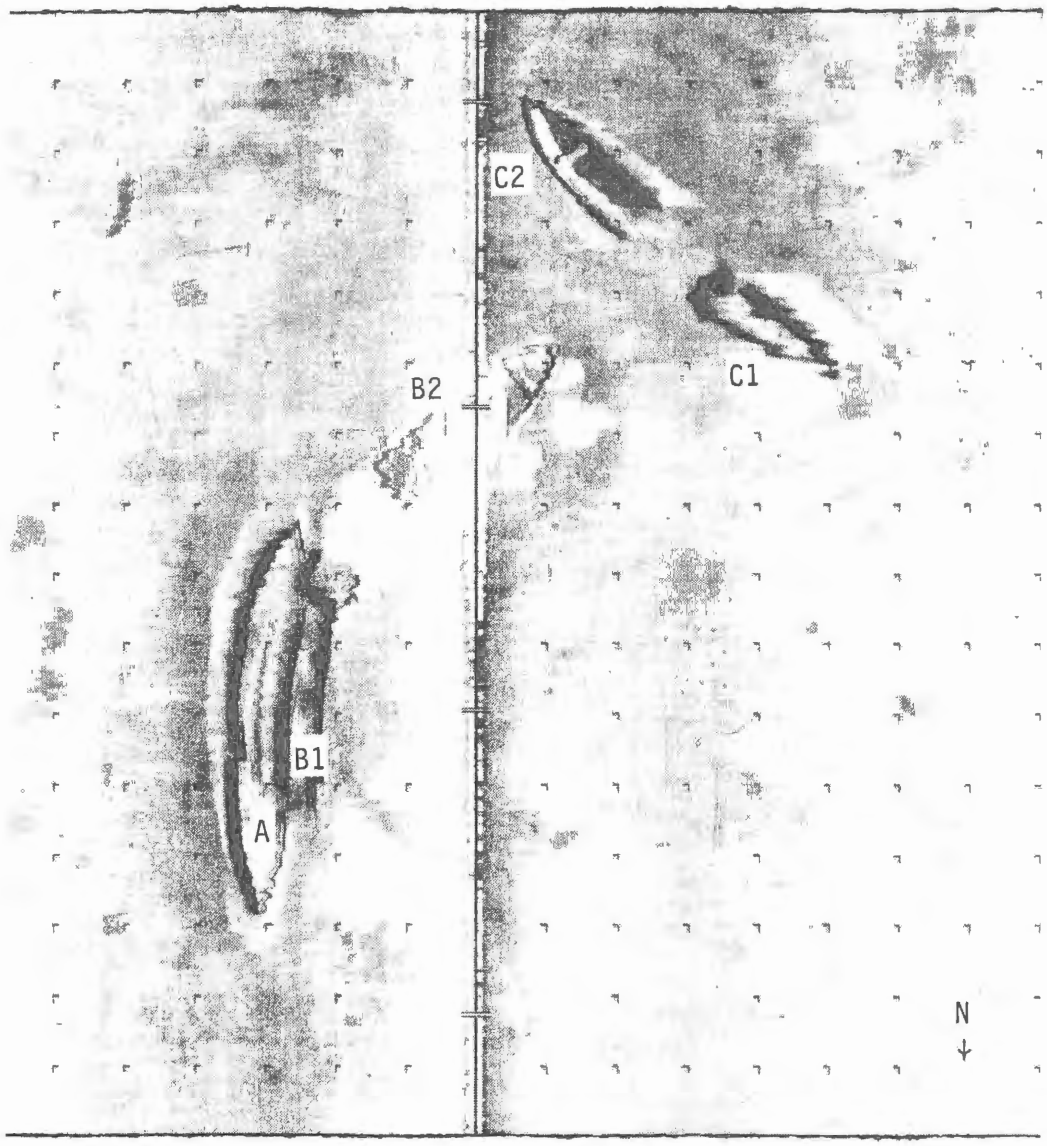

Figure 20. Liberty ship hulls at site FH-6. Target A is an intact hull, while targets B1, B2, C1, and C2 are halves of two other hulls. Scale along-track is 21.3 m/cm and across-track is 12.6 m/cm.

APPENDIX 2

SUBSIDENCE INDEX

During 1984, under a contract between the Mississippi Cooperative Extension Service's Sea Grant Advisory Service and the Mississippi Gulf Fishing Banks, Inc., a study was conducted to develop a method to monitor and assess artificial reef materials which had been deployed offshore of Mississippi (Lukens and Cirino, 1985). That study employed SCUBA divers to determine the precise position of materials, measure the height of materials off the bottom, and make general observations of the condition of materials.

Due to the silty mud composition of the bottom sediments in the waters offshore of Mississippi (Lukens 1980 and Jones, et. al. 1986), subsidence of materials was of special concern to the Mississippi Gulf Fishing Banks, Inc., the group responsible for management of the artificial reefs investigated. Documentation of the vertical height of the Liberty ship hulls and barges, which are the primary materials found on the artificial reefs investigated, provided a baseline of data with which to compare later measurements.

Subsequent measurements (Lukens and Cirino, 1986) indicated differences in resulting values from the baseline; however, since some measurements increased and some measurements decreased, it was difficult to ascertain with any degree of certainty if a general trend was occurring. This problem led to the development of the Subsidence Index, which is designed to detect any general trend toward subsidence of artificial reef materials over time. It should be pointed out that the measuring technique and the Subsidence Index were designed specifically for materials such as ship hulls and barges and may not conform adequately to application to other types of materials.

On any given ship hull or barge, four measurements were made. For consistency, these measurements were always made at the same location on each structure. Basically the Subsidence Index combines the four measurements in a formula to give a single number which serves as the index for a specific piece of material. That formula is:

$$SI = M_1 + M_2 + M_3 + M_i \ / \ i \ / \ 100$$

where SI = Subsidence Index, M = measurement, and i = number of measurements.

As an example of the application of the Subsidence Index, four hypothetical measurements from a Liberty ship hull will be used. Those measurements (in inches) represent the vertical distance from the bow (B), midship starboard (MS), midship port (MP), and the stern (S) of the ship hull to the substrate over four years of sampling.

	Year 1	Year 2	Year 3	Year 4
B	145	141	144	120
MS	138	139	122	137
MP	122	111	118	126
S	161	143	150	145
SI	1.42	1.34	1.34	1.32

It is not evident from a comparison of the individual measurements that any subsidence is occurring. However, a quick look at the Subsidence Index can give some indication as to what may be occurring. In the example, it does not appear that any significant subsidence has occurred over the four years of monitoring; however, since a downward trend is evidenced, the manager of this artificial reef would be wise to continue to monitor the structure in question, since if the trend continued it would result in loss of the structure and loss of the effectiveness of the artificial reef. In other cases where a time series of data on specific structures indicates no downward trend, sampling frequency could be modified to maximize program funds by concentrating primarily on those structures most at risk.