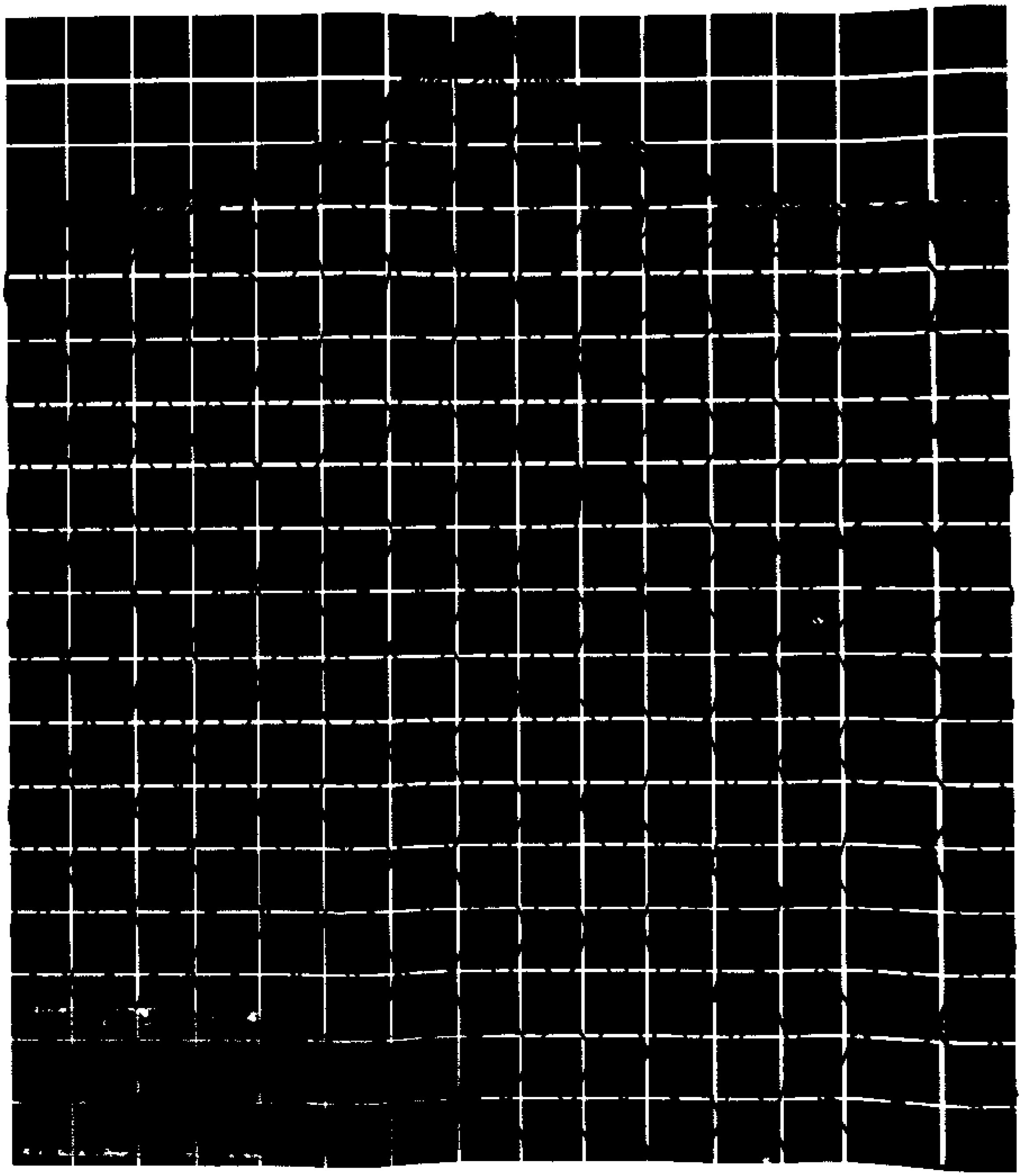
SHRIMP TRAWL DESIGN AND PERFORMANCE



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This publication is dedicated to the memory of

CAPTAIN FRANCIS J. CAPTIVA
SEPTEMBER 19, 1913–AUGUST 19, 1985

who was greatly respected and admired for his many contributions to the commercial fishing industry worldwide. He gave unstintingly of his time to assist in research and development efforts throughout his career as a commerical fisherman, a fishing gear specialist with the National Marine Fisheries Service and its predecessor organization, a technical writer for industry trade journals, and an advisor to industry, government, and Sea Grant Colleges. "Kaky," as he was known to his friends and colleagues, made a lasting impact on the fishing industry, and he will be sorely missed.

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PREFACE

In 1958 the U.S. Bureau of Commercial Fisheries produced a film on trawls which was used by the shrimp fishing industry in the Gulf of Mexico and southeastern U.S. waters. Consisting largely of underwater scenes of shrimp trawls towed under simulated fishing conditions, the film provided a great deal of insight into the functioning of fishing gear during actual harvesting operations and was considered a valuable instructional tool.

In the last 15 to 20 years, many modifications have been made to shrimp fishing gear by the industry, the National Marine Fisheries Service, and the Georgia Sea Grant College Program. The twin-trawl system was developed initially by shrimp fishermen in the Gulf of Mexico prior to World War II and subsequently modified by The University of Georgia's Marine Extension Service staff at the Fisheries Extension Center at Brunswick, Georgia. The twin-trawl system was gradually accepted by the shrimp industry, and now it is commonly used in the Gulf of Mexico, along the southeastern coast of the U.S., and in other parts of the world.

The success of the twin-trawl system provided the impetus to make further gear improvements to meet the needs of an industry fishing on three major species of shrimp on various types of bottom. Many of these efforts involved the collaboration of both the fishing industry and the National Sea Grant College Program, particularly the Georgia and Texas Sea Grant Programs. A new class of trawls, the tongue trawl, evolved. Different types of tongue trawls, bearing such colorful names as the mongoose, cobra, scorpion, and the spider mongoose, reflect the ingenuity and insight of individual fishermen, net makers, and Sea Grant Advsiory Service specialists. Each has its advantages and disadvantages, and each has its supporters within the industry.

The twin-trawl and tongue-trawl systems represent a significant step in the evolution of shrimp fishing gear. The superior harvesting capability of these systems over the traditional double-rigged nets that had been used for many years was readily recognized, but no visual evidence of the behavior of these trawls underwater existed and there was a notable lack of quantitative information on the performance of these systems. It was important, therefore, to conduct underwater tests and observations of the new trawl systems for comparison with the traditional nets. Consultation with industry and the National Marine Fisheries Service elicited strong endorsement of the effort to carry out these evaluations.

Because this project was of major significance to the entire shrimp fishing industry in the southern U.S., it was undertaken as a regional project by the Southeastern Marine Advisory Services, an informal association of the marine advisory service components of the Sea Grant Programs from North Carolina to Texas. In line with this commitment, these Sea Grant Programs provided funds and staff to support the project. Major contributions came from the National Marine Fisheries Service and representatives of the shrimp industry, including fishermen, packers, processors, marine supply houses, and a trade association. A detailed list of the contributors is provided in a separate section.

The field work was carried out in May 1984. In 1985 the film which resulted from this project was made available in 16 mm and video cassette form. This paper supplements the film and provides additional details and data which could not be included in the film.

It is obvious that this project could not have been carried out without the collaborative effort of GOVERNMENT (the National Oceanic and Atmospheric Administration's diving team and National Marine Fisheries Service), *UNIVERSITIES* (the Sea Grant College Programs from North Carolina to Texas), and *INDUSTRY*. In this sense, the project is a classic example of how the founders of the National Sea Grant College Program intended the program to work.

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CONTENTS

TABLES

INTRODUCTION

Shrimp trawl designs have changed dramatically in the past decade. New nets, doors, and bridle arrangements offer shrimpers more choice. Selecting the most effective and efficient system for a particular area and situation is difficult. Shrimp fishing with trawls is a high-energy activity, and proper gear selection is extremely important to maximize production and minimize fuel consumption.

In response to the need for gear research expressed by the shrimp harvesting industry, the Sea Grant College Programs in the southeastern and Gulf states joined with the National Marine Fisheries Service (NMFS) to evaluate the performance of major trawl systems used by the U.S. shrimp industry along the southeastern and Gulf of Mexico coasts.

In May 1984, field trials were conducted off the Bimini Islands in the Grand Bahamas using the GEORGIA BULLDOG, a fisheries research vessel operated by The University of Georgia's Sea Grant College program. This site was chosen because of its water clarity and clean bottom, features needed for underwater observation and photography. The results are presented in this report.

Underwater observations made of the various trawl systems under tow were documented on 16 mm color film, copies of which are available through loan arrangements with the participating Sea Grant College Programs and the National Marine Fisheries Service. Films and video cassette tapes in English and Spanish editions are available for purchase from The University of Georgia, Center for Continuing Education, Athens, Georgia 30602.

GEAR, EQUIPMENT, AND GENERAL METHODOLOGY

VESSEL

The GEORGIA BULLDOG is a 72-ft DESCO wooden shrimp trawler powered by a D-343 Caterpillar engine on a 6:1 reduction gear with a 60-inch diameter, 50-inch pitch propeller. Converted for multipurpose fishing, the vessel has a stern ramp, fish trawl reel, longline reel, and port and starboard stern gallows.

STANDARD TOWING METHOD

Standard methods established to test the performance of the various trawl systems included a tow speed of 2.5 knots at water depths from 20 to 30 ft. Since there was essentially no tide or current, we were able to use a water flowmeter to measure towing speed over the bottom. The flowmeter, a General Oceanics Model 2030 with visual voltage readout, was calibrated regularly and read frequently during each tow.

TRAWL SYSTEMS TESTED

The trawl systems used in the trials were selected on the basis of a survey of industry interests. The Marine Advisory Service units of the participating Sea Grant College Programs and the National Marine Fisheries Service at Pascagoula, Mississippi, consulted shrimp fishermen, net builders, net shop operators, shrimp associations and others to determine priorities.

Eight trawl systems were used in the standard performance tests. They included four which have been used for many years (the flat, two-seam, semi-balloon, and western jib trawls); a twin trawl which has come into use since the early 1970s; and three tongue trawls which evolved from the twin trawl (mongoose, three-wing, and scorpion). All were constructed of No. 15 nylon twine, 1⅞-inch stretched mesh which is the size most commonly used by the industry.

In addition, we studied the performance of a Burbank twin spider mongoose trawl system towed with different types of bridles, a 50-ft flat net with and without a bib, and two box trawls. We also conducted tests to determine how various factors, such as flotation, towing speed, tickler chain settings, length of the tongue wire, twine size and area, and door size, affected the efficiency and performance of different trawl systems. An original objective was to determine differences in performance using wooden, aluminum, and plastic trawl doors. Time was insufficient to permit thorough evaluation of these doors, however, and results were inconclusive.

TRADITIONAL TRAWLS

General specifications for the four traditional trawls used in the standard tests were (1) headrope length of 50 ft, (2) no floats, (3) bridle length of 40 fathoms, (4) 7-ft by 36-inch wooden doors, with 9.5 inches dropback made with 5 links of ⅜-inch chain and one ⅜-inch shackle. The term "dropback" refers to the extension of the bottom leglines.

FLAT TRAWL. The flat trawl has been used by the shrimp industry since the early 1900s. It has less overhang and makes closer bottom contact than the semi-balloon. In the corner piece, hanging meshes are points and usually are hung on one-third (33%). After prolonged use, the webbing in the corner pieces becomes distorted as a result of the towing strain which is transferred along the bars of the webbing. Accordingly, the meshes of the corner pieces tend to become rectangular, making it difficult to mend the webbing (Appendix Figure 1).

TWO-SEAM BALLOON TRAWL. The two-seam balloon trawl consists of top and bottom panels sewn together to form the body of the trawl (Appendix Figure 2). In contrast to the flat trawl, all of the hanging meshes of the corner pieces are on bars and generally are hung 100%. The two-seam balloon spreads more easily than the flat net, but by its design, the headrope cannot reach theoretical maximum height. Under tow, the mouth of the net assumes an elliptical shape. Distortion and damage at the juncture of the corner pieces and mouth may be a problem, but this can be alleviated with the addition of a jib piece and/or belly lines at the juncture.

FOUR-SEAM SEMI-BALLOON TRAWL. The four-seam semi-balloon (Appendix Figure 3) was created by splitting the seam of the two-seam design and inserting a side panel (wing). For strength at the quarters where the corner and body of the net join, a small jib piece is added. The trawl is hung to the headrope and footrope as with the balloon trawl, but it assumes the rectangular shape of a flat trawl when towed. This trawl requires slightly more netting than the balloon or flat trawl.

WESTERN JIB TRAWL. The western jib trawl made its appearance on Gulf coast shrimp boats in the early 1960s. This net differs from others in its corner pieces which are designed to transfer more of the strain on the wing netward (Appendix Figure 4). This action provides the wings with greater spread than the three nets described above. These corner pieces are cut so the points are sewn to the wings. Each corner piece has a one mesh/two bar taper which is sewn to the body. This allows the netting to pull in the same direction as the wings and body, reducing distortion in the corner pieces.

TWIN TRAWLS

With the collaborative effort in developing the twin-trawl system by the Georgia Sea Grant College Program and industry in the early 1970s, more and more shrimp fishermen have switched to twin trawls for improved efficiency (Harrington *et al.*, 1972).

Twin trawls require a third bridle wire attached to a dummy door, or sled (Figure 1).

They can be rigged of any trawl design, yet they use significantly less webbing than single trawls with similar headrope lengths. The advantage of twin-trawl systems is that, with the same horsepower, a boat can tow four small nets with greater headrope length than two large nets rigged in the conventional way. They can be handled as easily as comparable size traditional nets, and they can be fished as a single unit off the stern, or as a double rig, one off each side of the boat.

TWIN 35-FT FLAT TRAWL. The twin-trawl system used in our standard tests consisted of two flat nets each with a headrope length of 35 ft, no floats, bridle length of 40 fathoms, 7-ft by 36-inch wooden doors, and a dummy door, or sled, 6 ft long by 40 inches high. The bottom leglines on the doors had a dropback of 9.5 inches (Figure 2A and Appendix Figure 5).

TONGUE TRAWLS

The successful operation of the twin-trawl system and its subsequent acceptance and further modification by the commercial fishing fleet led to the development of the tongue trawl (Figure 3). The tongue is a forward extension of the middle part of the net, usually the upper part only. It improves the spread of the net by distributing the towing force more evenly across the net and away from the doors. Except for such systems as the three-wing trawl which has another tongue on the bottom part of the net (Figure 4), most tongue trawls require a three-wire bridle system, one wire leading to each door and a middle wire leading to the tongue. The middle wire requires an extension for proper rigging.

With the success of the tongue trawls, many fishermen modified their conventional nets, such as the flat, semi-balloon, and Captiva Super X-3 (Appendix Figure 10), by extending the middle section of the upper part of the net with a triangular piece of webbing, or bib (Figure 5). These rigs are often referred to as bib trawls. In concept and function, they differ little from tongue trawls. Both "bib" and "tongue" refer to an extension of the middle part of the leading edge of the net. They have reportedly produced better catches, especially in shallow water white shrimp fisheries. In a tongue trawl, the extension is usually constructed as part of the original net (Figure 3), whereas in a bib net it is a separate piece sewn into the headrope of a conventional net, and it is clearly distinguishable from the body of the original net (Figure 5). Both types of trawls are towed with an extra bridle wire attached to the extension.

Bibs can be installed in several ways: (1) from inside corner to inside corner, (2) by adding small jibs to prevent the hangings and netting from tearing out at the junction of the bib and corner piece, (3) by using short bellylines to replace the jibs, and (4) by running the base of the bib past the corner junction. Other variations are to sew the base of the bib directly to the headrope combination cable and rehang the entire headrope as in the mongoose, or sew the bib to the net two or three meshes down from the hanging meshes.

The three tongue trawls used in the standard tests (mongoose, three-wing, scorpion) measured 50 ft along the headrope, were towed with 40 fathom bridles, and spread with 7-ft by 36-inch wooden doors, with 9.5 inches dropback. The extension of the top middle bridle wire was 9 ft.

MONGOOSE TONGUE TRAWL. The mongoose (Appendix Figure 6) is regarded by many fishermen as one of the most significant improvements in shrimp trawl design in the past 50 years. It is unique because the corners, jibs, tongue, and body panel are cut from one rectangular piece of netting. Along the southeastern U.S. coast, the mongoose is fished either as a single trawl or in a twin-trawl system and has frequently out-produced many conventional trawls. Its greater efficiency is presumably due to greater horizontal spread and vertical opening.

THREE-WING TONGUE TRAWL. The three-wing tongue trawl, shown in Figure 4, is similar to the mongoose, but it has an additional tongue on the bottom part of the net and requires a four-wire bridle. The third wire leading to the upper tongue is of smaller diameter. The fourth wire is attached to a modified sled (lower profile than that described in Harrington *et al.*, 1972), which is attached in turn to the bottom tongue. Some fishermen use a "bullet" or heavy pipe in place of the sled. In this study we used the bullet rig. Setback is produced by making the bottom corner piece longer and narrower than the top corners (Appendix Figure 8). The term "setback" refers to the distance that the footrope pulls behind the headrope and is measured as the difference between the "hung-in" portion of the headrope and footrope.

SCORPION TONGUE TRAWL. This net is another modification of the basic tongue trawl. It incorporates a top panel like the mongoose and a bottom panel like the Captiva Super X-3 and combines desirable features of both designs. The bottom corners are similar to those of the Captiva net (Appendix Figure 10). However, in the scorpion net, a small jib is added where the corner attaches to the mouth on the bottom body panel (Appendix Figure 9).

TWIN TONGUE-TRAWL SYSTEMS

Many shrimp fishermen in the southeast tow twin tongue trawls off each side of the boat. Only one of these systems, a Burbank twin 48-ft spider mongoose trawl, was evaluated to provide general information on the performance of this type of trawl. This is simply a mongoose trawl rigged to fish as a twin trawl. The net was modified by the addition of triangular wedges of webbing sewn onto the forward edge of the wing where the brail line normally would be and attached to the back edge of the trawl door (Figure 6). This is commonly called spider mongoose trawl or a mongoose trawl with spider wings.

The purpose of the wedge-like extension is to put a strain on the leading edge of the net wings and eliminate the slack webbing found commonly in the forward section of the wings of conventional trawls under tow. The strain provided by the spider wings also makes it easier for the headrope to rise. The wedges also provide additional webbing coverage between the doors and the net.

BOX TRAWLS

Box trawls have been fished in the northwestern Gulf of Mexico since the late 1930s. They are generally considered to be "hard fishing nets" (dragging near bottom), and they are used mostly by inshore fishermen in the bay shrimp fishery. Some Gulf shrimpers use small box trawls as trynets.

Although box nets are reputedly productive for harvesting shrimp, they generally lose efficiency with increasing size. Texas bay fishermen commonly use 25- to 30-ft box trawls during seasons when they are limited by law to smaller nets. The 40- to 50-ft nets are not popular because they require large amounts of webbing and are less efficient.

General observations were made of a 25-ft and a 50-ft box trawl under tow. The 50-ft trawl had too much webbing, most of which was slack. The footrope dug in hard in the center section and was 8 to 10 inches above the bottom in the wing sections. The trawl did not fish properly, and tests of this gear were discontinued.

In contrast, the 25-ft box trawl performed well and did not exhibit the slack webbing characteristics of the 50-ft trawl.

FACTORS USED TO EVALUATE THE PERFORMANCE OF VARIOUS TRAWL SYSTEMS

The major characteristics used to compare the performance of the eight trawl systems included (1) headrope height, (2) footrope height, (3) net spread, (4) spread ratio, (5) twine area, and (6) towing tension.

HEADROPE HEIGHT, measured with a calibrated plastic rod under towing conditions, is the distance from the center of the headrope to the bottom. The height of the net is particularly important in harvesting white shrimp which are found higher in the water column than either the brown or pink shrimp.

FOOTROPE HEIGHT is the distance from the footrope to the bottom.

NET SPREAD is the width of the net opening from the first hanging on the headrope of each wing, not including the leglines or doors, while the net is under tow. It is essentially a measurement of the horizontal spread of a net and was measured with a calibrated wire attached to the tip of one wing and stretched through a pulley system to the opposite wing.

SPREAD RATIO is the spread of the net divided by the length of the headrope, and it is presented as a percentage of the headrope length.

TWINE AREA is the surface area covered by the net material as though the net material were one flat piece. It is a fixed measurement, and it is useful in comparing different type nets. For example, the 35-ft twin trawls have essentially the same twine area, or amount of webbing, as most single 50-ft tongue trawls.

TOWING TENSION is an estimate of strain on the tow cable, and it is an indicator of the amount of drag created by the trawl system, which, in turn, has a direct effect on fuel consumption. Towing tension is closely related to twine area. We measured towing tension with a Transducers (C.E.L.) Ltd. Load cell, Model 9-6210 series strain indicator, which was calibrated before each tow and monitored constantly during the tow.

Other factors considered, depending on the circumstances, included fuel consumption, tickler chain settings, and trawl door angle of attack (AOA) resulting from different door chain settings. Observations on gear behavior, such as bottom tending, heeling, and nosing of the doors, were noted.

RESULTS

PERFORMANCE OF 50-FT AND TWIN 35-FT TRAWLS

The twine area and performance characteristics of the eight major trawls tested are shown in Table 1. The trawls were towed under standard conditions as described above.

The tongue trawls out-performed standard trawl designs when both net spread and rise are considered. They had the best spread ratio (78 to 85%) of all nets tested and the best spread (39 to 42.5 ft). Their headrope heights of 3.5 ft were exceeded only by the four-seam semi-balloon. Tongue trawls, however, generally require more webbing than conventional single trawls. The three-wing and mongoose trawls had the greatest twine area (271 sq ft), which is reflected by the highest towing tensions of 2,100 and 1,800 pounds, respectively. In the three-wing trawl the weight of the "bullet" attached to the bottom tongue and the resulting friction as it rode over the bottom undoubtedly increased the towing tension. The greater spread of the three-wing trawl over the mongoose also contributed to the greater towing tension.

Table 1
Trawl Performance Summary for Twin 35-Ft Trawls and Seven 50-Ft Trawls

Trawl	*Spread (ft)*	*Spread Ratio (%)*	*Headrope Height (ft)*	*Footrope Height (inches)*	*Twine Area (sq ft)*	*Towing Tension (lbs)*
Flat	37.0	74	3.0	3	213	1,350
Two-seam balloon	38.5	77	2.75	0	201	1,350
Four-seam semi-balloon	37.0	74	4.0	3	248	1,400
Western jib	39.0	78	2.5	3	233	1,700
Twin	56.0	78	3.0	2–3	267	1,750
Mongoose[b]	39.0	78	3.5	4	266	1,800
Three-wing tongue[a]	42.5	85	3.5	0	271	2.100
Scorpion[b]	41.5	83	3.5	3	226	1,750

[a]Top middle bridle wing extension, 9 ft; bottom middle bridle wing extension, 10 ft (5-ft bullet + 5-ft chain)
[b]Middle bridle extension, 9 ft

The relation between twine area and towing tension (Figure 7) indicates that twine area is a good indicator of drag and, therefore, of efficiency in terms of fuel consumption. The three-wing trawl which has the greatest twine area shows 10% greater spread but 55% more drag than the two-seam balloon trawl which has the least twine area. Therefore, it is reasonable to assume that the balloon trawl would be more fuel efficient but less efficient in catching shrimp.

The twin-trawl system was very efficient compared to the traditional nets. Studies on energy efficiency of shrimp trawl designs indicate that twin trawls sweep a larger area per gallon of fuel expended than do conventional trawls (Watson *et al.*, 1984).

The efficiency of the twin trawls was confirmed by the results of this study. The twine area of the twin trawls (267 sq ft) was similar to that of the three-wing and mongoose tongue trawls. However, the spread of 56 ft was considerably greater than that for either tongue trawl (42.5 and 39.0 ft, respectively), and the towing tension, indicative of drag and fuel consumption, was less than that for either. Even the scorpion tongue trawl which had far less twine area than the twin trawl showed the same towing tension.

EFFECT OF A BIB ON TRAWL PERFORMANCE

To determine the effect of adding a bib to a conventional trawl and essentially converting it into a tongue net, we towed a 50-ft flat trawl with six 6- by 8-inch Spongex floats attached to the headrope, first without a bib and then with a bib sewn onto the top part of the net. In both trials, the trawl was spread with 7-ft by 36-inch doors and towed at 2.5 knots. The bib was hung on ⅝-inch diameter three-strand poly-dac rope which was tied and tucked into the existing combination cable. The webbing in the tongue was sewn to the top body three meshes down from the hangings. The middle bridle leading to the bib had a 7-ft extension. Details are shown in Figure 5 and Appendix Figure 7.

The results, in Table 2, show that the addition of a bib resulted in 6 ft more spread and 2 ft more height, which provides the basis for its greater harvesting efficiency over the conventional trawl.

Table 2 Effect of Bib on Trawl Performance					
	Spread (ft)	*Headrope Height (ft)*	*Footrope Height (inches)*		*Towing Tension (lbs)*
			Center	*Wings*	
With bib	39	8.5	2–3	8–10	1,650
Without bib	33	6.5	4	10–12	1,500

EFFECT OF FLOTATION ON TRAWL PERFORMANCE

Floats attached to the headrope presumably affect the performance of trawl systems by changing the height and spread of a net. We studied the effects of flotation by varying the number of floats on four different trawl systems towed under the standard conditions described above. The systems used were the 50-ft flat, semi-balloon, mongoose, and scorpion trawls. All were rigged with 0 to 18 Spongex floats (6 by 8 inches) except the scorpion which was rigged with 0 to 6 floats.

The results, shown in Table 3, show dramatic changes in height and spread associated with the amount of flotation. With 6 floats, the headrope height of the mongoose net was recorded at 7.5 ft. With 18 floats, it rose to 13 ft, but the spread was reduced from 37 to 30 ft. With the same number of floats, the headrope height of the flat trawl was 1.5 to 2 ft higher than that of the semi-balloon net.

The amount of flotation had a significant effect on towing tension, or drag (Table 3). The mongoose net equipped with 18 floats had the highest towing tension of 2,150 lbs. It is noted, however, that the extension of the middle bridle wire of the mongoose

Table 3
Effect of Flotation on Trawl Performance

Trawl Type	*No. of Floats*	*Middle Wire Extension (ft)*	*Spread (ft)*	*Spread Ratio (%)*	*Headrope Height (ft)*	*Footrope Height (inches)*		*Towing Tension (lbs)*
						Center	*Wings*	
Semi-ballon	18	—	31	62	8.0	3–6	—	1,700
	12	—	32	64	7.0	3–6	—	1,500
	6	—	33	66	5.5	3	—	1,450
	0	—	37	74	4.0	3	—	1,400
Flat	18	—	31	62	10.0	4–6	12–15	1,650
	12	—	31	62	8.5	4	12–15	1,700
	6	—	33	66	6.5	4	10–12	1,500
	0	—	37	74	3.0	3	4	1,350
Mongoose	18	12	30	60	13.0	8	14	2,150
	12	12	34	68	11.0	6	12	2,100
	6	12	37	74	7.5	6	10	2,000
	0	9	39	78	3.5	4	—	1,800
Scorpion	6	7	38	76	5.0	3	—	—
	4	7	39	78	4.5	4	—	—
	0	9	41.5	83	3.5	3	—	1,750

and scorpion trawls used in the standard test (no floats) was 9 ft. In these flotation tests, the middle bridle wire extension was 12 ft on the mongoose and 7 ft on the scorpion.

Shrimpers fishing with tongue trawls commonly use a longline float attached to the forward part of the tongue. Some encase the float in webbing to reduce the amount of drag and to keep the float from being tangled with other parts of the net. To determine if this webbing had any significant effect on flotation, we towed a 50-ft mongoose tongue trawl with a float encased in webbing, then with a bare float, attached to the tongue.

The results were contrary to the beliefs of many fishermen. With the float encased in webbing, the headrope reached a height of 12 ft; with the bare float, it reached a height of 14 ft. The webbing around the float reduced its friction when pulled through the water. Consequently, as drag or friction is a function of lift, the float not encased in webbing has more lift.

EFFECT OF TOWING SPEED ON TRAWL PERFORMANCE AND FUEL CONSUMPTION

In addition to such factors as drag of the net and doors, towing speed is critical to fuel consumption and the performance and efficiency of a trawl system. To investigate the effects of different towing speeds, we towed a single 50-ft flat net at various speeds from 2.0 to 5.0 knots. The net was spread with 7-ft by 36-inch doors, and fuel consumption was measured with a subtraction type fuel monitoring system, ECI Marine, Model 202. Unlike the flat net used in the standard tests, this net was constructed of No. 18 twine. The results are shown in Table 4. *Readers should note that the low fuel consumption rates are a result of towing with a single net.*

At 2.0 knots, trawl spread ratio was 66% and towing tension was 1,100 pounds. However, the footrope of the net "fished hard" (dug in) on the bottom, and the doors were unstable. Fuel consumption of 2.2 gallons per hour (gph) was noted.

At 2.5 knots, the spread ratio increased to 70% and towing tension to 1,500 pounds. The footrope was 3 inches from the bottom. The doors were stable, and the net fished properly. Fuel consumption increased to 3.2 gph.

Table 4
Effects of Towing Speed on Performance and Fuel Consumption Using a Single 50-Ft Flat Net

Speed (knots)	*Net Spread (ft)*	*Spread Ratio (%)*	*Headrope Height (ft)*	*Footrope Height (inches)*		*Towing Tension (lbs)*	*Fuel Consumption (gph)**
				Center	*Wing*		
2.0	33	66	3.0	0	4	1,100	2.2
2.5	35	70	3.5	3	4	1,500	3.2
3.0	37	74	3.5	3–4	6	2,300	4.2
3.5	35	70	4.0	6–8	8–12	3,000	7.6
4.0	Gear off bottom			—	—	3,500	8.0
5.0	Gear off bottom			—	—	4,700	15.3

*Fuel consumption lower than that in normal commercial operations, which usually involves towing two trawl systems.

At 3.0 knots, the spread ratio increased to 74%, but towing tension was 2,300 pounds, and fuel consumption increased to 4.2 gph. The footrope was 4 inches off the bottom, but the trawl and trawl doors were stable.

At 3.5 knots, the spread ratio decreased to 70% while towing tension increased to 3,000 pounds, and fuel consumption increased to 7.6 gph. At this speed the footrope was 7 inches off the bottom which is considered too high for harvesting shrimp.

At 4.0 knots, the net and doors came completely off the bottom. Although observations were difficult at 5.0 knots, the net was well off the bottom, and performed poorly.

Based on the results of this study, it is obvious that the optimum towing speed was between 2.5 to 3.0 knots. At this range, the spread ratio was greatest and enabled the net to fish over the maximum bottom area. Fuel consumption was between 3.2 and 4.2 gph. If we assume the optimum towing speed to be 2.75 knots, a towing speed of only 3.5 knots results in a 105% increase in fuel consumption. At a towing speed of 4.0 knots, fuel consumption increased 116%, and at 5.0 knots, it increased 313%.

EFFECT OF SIZE AND SETTING OF TICKLER CHAIN ON TRAWL PERFORMANCE

A tickler chain is used to cause shrimp to jump off the bottom and pass over the footrope into the net. Chain sizes used are usually 1/4 or 5/16 inch in diameter. To function properly the tickler chain is shorter than the footrope. This difference varies among fishermen.

The effects of different chain sizes and different chain settings on net performance and tickler chain profiles were studied. We used 1/4-inch and 5/16-inch chain on 50-ft flat nets, spread with 7-ft by 36-inch doors, with 9.5 inches dropback. The chain was set 36 inches shorter than the footrope. Following common industry practice, we attached the chain to the heel of each door. The results in Table 5 include comparable data from Table 3 based on the use of a similar net towed without a tickler chain. The 1/4-inch chain increased net spread by 2 ft over the 5/16-inch chain and by 1 ft over the net towed without a tickler chain. It fished further ahead of the footrope, and did not cause the footrope to dig into the bottom as much as the 5/16-inch chain.

Table 5
Effect of Tickler Chain Size on Net Performance

Chain size (inches)	5/16	1/4	No chain
Net spread (ft)	36	38	37
Headrope height (ft)	3	3	3
Footrope height (inches)	0	3	3
Distance tickler ahead of footrope (inches):			
Center	19	24	—
Wing	9	15	—
Towing tension (lbs)	1,530	1,540	1,350

Using 1/4-inch chain, we investigated the effects of different tickler chain settings, ranging from 24 to 48 inches shorter than the footrope. For comparison with the traditional industry practice of attaching the chain to the heel of the door, we also

Table 6
Effects of Different Tickler Chain Settings on Trawl Performance

Inches Shorter Than Footrope	*Net Spread (ft)*	*Distance Tickler Chain Ahead of Footrope (inches)*	
		Center	*Wing*
24	37.5	18	8–10
36	38.0	24	15
48	35.5	32	18
36*	37.5	24	20–24

*NMFS arrangement (chain attached 21 inches ahead of heel of door)

tested a tickler chain arrangement recommended by the National Marine Fisheries Service (NMFS). The results are shown in Table 6.

When it was set 24 inches shorter than the footrope, the tickler chain fished 18 inches ahead of the footrope at the center but only 8 to 10 inches ahead of the wings. With the chain 36 inches less than the footrope, it fished 24 inches ahead of the footrope at the center and 15 inches in front of the wings, and net spread increased by 6 inches.

When the tickler chain was 48 inches shorter than the footrope, it fished 32 inches ahead of the footrope at the center and 18 inches ahead of the wings. However, net spread decreased 2 to 2.5 ft from the previous two settings, showing that the 48 inch setting is unsuitable.

Earlier work by the NMFS indicated that the tickler chain will fish more evenly along the entire footrope if the attachment point is moved forward on the inside face of the trawl door. Using a chain 6 inches longer than the footrope, we attached it to the door 21 inches forward of the heel of the door (Figure 8). This arrangement is essentially equivalent to a tickler chain 36 inches shorter than the footrope. The results are also shown in Table 6. With this arrangement the tickler chain fished 24 inches in front of the footrope at the center. Compared to the same length tickler chain attached in the traditional way (to the heel of each door), the distance in front of the footrope was the same at the center, but 5 to 9 inches greater at the wings. The divers also noted that throughout its length the tickler chain was ahead of the leglines. These results and observations confirm the advantages of moving the attachment point forward.

EFFECT OF TWINE SIZE ON TRAWL PERFORMANCE

As noted above, twine area (total surface area of a net), affects the towing tension, or drag, of a trawl. Twine area, however, is affected in turn by the size of the twine used. To study the effect of twine size on twine area and trawl performance, we compared two 50-ft flat nets, one constructed with No. 15 twine and the other with No. 18 twine. The twine area of the net made with the heavier twine (No. 18) was 32 sq ft greater than that of the net made with No. 15 twine.

The results are shown in Table 7. At the standard tow speed of 2.5 knots, the net made with No. 15 twine had a spread of 37 ft and a towing tension of 1,350 lbs. The heavier net spread only 35 ft with the tension increasing to 1,500 lbs. Thus the increase in twine size from No. 15 to 18 not only increased the twine area, but reduced the spread of the net and increased the tension and fuel consumption.

Twine Size	No. 15	No. 18
Twine area (sq ft)	213	245
Towing tension (lbs)	1,350	1,500
Headrope height (ft)	3	3.5
Footrope height, center (inches)	3	3
Footrope height, wings (inches)	4	4
Net spread (ft)	37	35
Spread ratio (%)	74	70

Table 7
Effect of Twine Size on Trawl Performance

EFFECT OF DOOR SIZE AND ANGLE OF ATTACK ON TRAWL PERFORMANCE

To determine the effect of door size on trawl performance, we used several sizes of wooden doors to spread the twin 35-ft flat trawls and the 50-ft flat, semi-balloon, and mongoose trawls. As in the standard performance tests, all tows were made at 2.5 knots.

The chain settings for the trawl doors are shown in Table 8 by the number of links of each chain. For simplicity, link counts started with the link in the chain plate, but the shackle was not included in the count. Using twin trawls with different size doors, we made several adjustments in rigging the dummy door (Figures 2B and 2C).

Table 8
Door Chain Settings for Wooden Doors Used

	Door Size	Chain	Links			
Trawl Systems	Length (ft) by Height (inches)	Size (inches)	Front Top	Front Bottom	Back Top	Back Bottom
All	6 by 36	3/8	20	19	35	34
All	7 by 36	3/8	21	20	41	40
Twin	8 by 40	1/2	19	18	37	36
All except twin	9 by 40	1/2	17	16	43	42

The results (Table 9) indicate that increasing the door size increased significantly the spread of the net, but it had no effect on the headrope height of the twin-trawl system and little effect on the footrope height of either the twin trawls or mongoose tongue trawl. With all systems, towing tension and fuel consumption increased with increasing door size.

Fishermen often vary the angle of attack (AOA) by the doors with the intent of obtaining greater fishing efficiency. This factor was studied by towing a 50-ft flat net made of No. 15 twine and spread with wooden 7-ft by 36-inch doors on which the angle of attack was varied by adjusting the two front chains. The results (Table 10) show that the AOA had little effect on net spread. All observations fell within the range of generally acceptable door settings. AOA values of 40 to 50° are often used for increasing door stability. However, increased AOA results in increased fuel consumption.

Table 9
Effect of Door Size on Trawl Performance

Trawl Type	Door Size Length (ft) by Height (inches)	Spread (ft)	Spread Ratio (%)	Headrope Height (ft)	Footrope Height (inches)	Towing Tension (lbs)	Fuel Consumption (gph)
Flat	6 by 36	33	66	3	2	1,250	2.7
	7 by 36	37	74	3	3	1,350	3.5
	9 by 40	42.5	85	3.3	4–6	2,100	4.0
Semi-ballon	6 by 36	34	68	3.5	0	1,350	3.6
	7 by 36	37	74	4	3	1,400	3.5
	9 by 40	42	84	3.5	6	2,400	4.2
Twin	6 by 36	52	73	3	1–2	1,700	3.8
	7 by 36	56	78	3	2–3	1,750	3.9
	8 by 40	61	85	3	2–3	2,400	5.1
Mongoose	6 by 36	35	70	2.5	2	1,500	2.6
	7 by 36	39	78	3.5	4	1,800	3.1
	9 by 40	43	86	3.5	3	2,350	3.9

BURBANK TWIN SPIDER MONGOOSE TRAWL

In towing twin tongue trawls, shrimp fishermen use two different bridle arrangements, but differences in their effect on trawling performance were not known. Both bridle systems involve the use of five wires.

The first type, referred to as the 3 + 2 bridle, has three main wires, each 300 ft long, and two short wires of 150 ft each (Figure 9). The two outside wires lead to the trawl doors, and the center one leads to the sled or dummy door. The two short wires lead from the halfway point of each outside wire to the tongue of each net. Some fishermen attach the short tongue wires higher up on the outside wires.

The second type, also shown in Figure 9, is referred to as the five-wire bridle and consists of five independent wires, 300 ft each.

Table 10
Effects of Different Door Chain Settings and AOA on Trawl Performance
(Wooden 7-ft by 36-inch doors and 3/8-inch chain used.)

Number of Links: Front Top Chain	Front Bottom Chain	Back Top Chain	Back Bottom Chain	AOA (deg)	Tilt (deg)	Net Spread (ft)	Fuel Comsumption (gph)
16	15	41	40	29	5	37.0	3.0
21	20	41	40	37	7	37.0	3.2
23	22	41	40	40	4	37.0	3.5

Both types of bridles were tested with the Burbank twin 48-ft mongoose nets with spider wings, the second type (five-wire) illustrated in Figure 10. In both types we used 8-ft by 40-inch wooden doors to spread the nets and a 6-ft by 36-inch sled (dummy door) in the center. All leglines were 8 ft with no dropback on the bottom legs. Eight 6- by 9-inch plastic floats were spaced along the headrope and a single 40-inch longline float was attached to each tongue. The wires leading to the tongues were extended by 10 ft.

The spider wings were adjusted differently on each net (refer to Figure 6). On one net, the leading edge of the wing was positioned 6 inches behind the vertical between the first hangings on the headrope and footrope. On the other net, the leading edge of the wing was positioned directly in line with the vertical between the first ties on the headrope and footrope. Divers noted that, with the latter arrangement, the trawl fished better, and they suggested that adjusting the leading edge of the wing 6 inches ahead of the vertical might be even better.

From diver observations and documentation on film, the performance of the Burbank trawl was impressive. The spider wings (Figures 6 and 10) took the slack out of the leading edge of the wings which allowed the headrope to start rising just behind the doors, an important factor in fishing for white shrimp. Net performance measurements (Table 11) show that the five-wire bridle resulted in 10 ft more spread with a loss of only 1 ft in net height, and achieved a greater spread ratio than the 3 + 2 bridle.

Table 11
Effects of Different Bridle Systems on the Performance of the Burbank Twin Spider Mongoose Trawl System

Bridle Wires	Spread (ft)	Spread Ratio (%)	Headrope Height (ft)	Footrope Height (inches) Center	Sled Wing	Door Wing
3 + 2	60	62.5	10	4	6–8	10–12
5	70	73	9	4	6–8	10–12

EFFECT OF MIDDLE WIRE EXTENSION LENGTH ON PERFORMANCE OF TONGUE TRAWLS

As noted above, most tongue trawls require a three-wire bridle system, one wire leading to each door and a middle wire leading to the tongue. For proper rigging, the middle wire must be lengthened with an extension. Time did not permit thorough testing to determine the optimum length of this extension, but enough observations were made to indicate the general effect of varying the middle wire length on trawl performance.

Table 12
Effect of Middle Wire Length on Performance of a Mongoose Tongue Trawl
(Wooden 7-ft by 36-inch doors)

No. of Floats	Length of Middle Wire Extension (ft)	Net Spread (ft)	Headrope Height (ft)	Footrope Height (inches)
0	8	38	3.7	4
0	9	39	3.5	4
0	10	39	3.2	4
6	12	37	7.5	
12	12	34	11.0	6
18	12	30	13.0	8

Tows were made with a 50-ft mongoose trawl rigged with the middle wire extended by 8, 9, 10, and 12 ft, and the results are presented in Table 12.

On the trawl rigged without floats, increasing the length of the middle wire extension from 8 to 10 ft appeared to have little effect except for a slight decrease in headrope height and increase in net spread. However, a middle wire extension of 12 ft, combined with the use of floats, increased the headrope height dramatically. With 6 floats, the headrope height increased more than twice without significant reduction in net spread. With additional floats, headrope height continued to increase, but net spread decreased considerably.

DISCUSSION

Three species of shrimp—brown shrimp (*Penaeus aztecus*), pink shrimp (*P. duorarum*), and white shrimp (*P. setiferus*)—make up the bulk of the shrimp catch in the Gulf of Mexico and along the southeastern U.S. coast. In terms of dollar value, they constitute the most valuable fishery in the U.S., and in 1985 the catch had an exvessel value of over $453 million.

Most fishermen would agree that there is no ideal trawl for harvesting every species of shrimp, under every fishing condition, in every area. For maximum fishing efficiency the most appropriate gear must be selected and modified to fit each situation. This study has provided data to permit comparing the performance of trawl systems that have been used for many years with systems that have been developed more recently. Underwater films of these trawl systems, towed with various rigging configurations, provide visual evidence of the effects of different adjustments to the gear. Both the film and the data presented in this paper should help fishermen understand the need to consider many factors in selecting and rigging their gear.

Biological and environmental factors, not under the control of fishermen, have a significant effect on shrimp harvesting. Differences in the biology and behavior of the three species are often related to environmental influences such as tides, wind, and bottom type. These factors require adjustment in fishing methods, gear selection and rigging details. The greater activity of brown and pink shrimp at night compared to white shrimp is well-known by the shrimp industry. These two species are usually found in closer association with the bottom than white shrimp, and in fishing for them, fishermen are more concerned with the spread of the net than its height. On the other hand, net height is more important in fishing for white shrimp, except during those periods of the year when water temperatures are low.

Fishing techniques and gear selection must take into consideration those features that lend themselves to fishing effectiveness. These include towing speed, length of tow, height and spread of the net, and height of the footrope. However, towing at high speeds and many changes in rigging to increase fishing effectiveness often result in increased towing tension and fuel consumption (Table 13). Other factors that increase towing tension include amount of twine used to construct the net, size of twine used, size of trawl doors, angle of attack (AOA) of the trawl doors, size and setting of tickler chains, amount of flotation used to raise the headrope, and bridling techniques.

The relationship between net height and net spread is known to most fishermen. One is achieved usually at the expense of the other, as shown in Table 14. The most effective trawl systems in producing net spread were poorest in net height, and vice versa. Between the extremes, several systems, such as the mongoose net rigged with six floats and the bib net provided reasonable performance in both net spread and net height. However, if fuel consumption is an important factor, the bib net is superior to the mongoose with six floats. The addition of a bib markedly improved the performance of a traditional 50-ft flat net by increasing its spread by 18% and its height

Table 13
Critical Features in Selecting Shrimp Fishing Gear

Factors Affecting Those Features	*Towing Tension and Fuel Consumption*	*Headrope Height*	*Net Spread*	*Footrope Height*
Towing speed	+ + +	+	+ + (−)	+ +
Twine area	+ +	0	+	0
Twine size	+ +	+	− −	0
Door size	+ + +	+ (−)	+ + +	+ +
AOA	+ +	0	0	0
Flotation	+ +	+ + +	− − −	+ +

+ = Slight positive correlation
+ + = Positive correlation
+ + + = Strong positive correlation
0 = No correlation
− = Slight negative correlation
− − = Negative correlation
− − − = Strong negative correlation
+ (−) = Slight positive correlation up to a point, then negative correlation
+ + (−) = Strong positive correlation up to a point, then negative correlation

by 31% (Table 2 and Figure 11). The cost of adding a bib to the flat net and converting it into a tongue net is relatively minor compared with the cost of purchasing a tongue net. Should there be need to convert back to a standard net, removal of the bib is a simple matter.

The observations on the twin-trawl systems explain why they have been accepted readily by shrimp fishermen, particularly in fishing for brown and pink shrimp, when net height is less important than net spread. Depending on the size of trawl doors used, the twin 35-ft flat trawls had net spread values ranging from 52 to 61 feet. Towing tension, however, was similar to or less than trawl systems with net spread values from 39 to 42 ft. This means a significant increase in the amount of area fished without any increase in fuel consumption.

Floats, attached to the headrope, increase net height, but reduce net spread (Figures 12 and 13). Moreover, increasing the number of floats also increases towing tension, and, thereby, fuel costs (Figure 14 and Table 14).

The studies on the effects of different tickler chain sizes suggest that both the proper size and setting are critical to optimum performance of trawls. Tests of 50-ft flat nets rigged with two different chain sizes (1/4 inch and 5/16 inch) showed that chain size had little effect on towing tension (Table 14). However, the larger size chain decreased net spread by 2 feet, which in turn caused the footrope to dig harder into the bottom (Table 5). The tickler chain setting is the difference between the length of the tickler chain and the longer footrope. As shown in Table 6, the 1/4-inch chain, set 36 inches shorter than the footrope, allowed greater spread than shorter or longer settings. It was surprising that this setting allowed 1 ft more spread on the same type of net without a tickler chain. These data suggest that 1/4-inch chain set at 36 inches is optimum for the size nets used in these tests.

Nets made with lighter twine (No. 15) had greater spread but less height than those made with heavier (No. 18) twine. However, the No. 15 net had less drag, and,

Table 14
Summary of Results on the Peformance of Trawl Systems Tested

Type of Trawl System	*Towing Tension and Fuel Consumption*	*Headrope Height*	*Net Spread*	*Spread Ratio*	*Footrope Height*
Traditional Trawls:					
*Flat (0), #18 twine	+ +	+	+ +	+ +	+ +
Flat (0)	+	+	+ + +	+ + +	+ +
Flat (6)	+ +	+ + +	+ +	+ +	+ + +
Flat (12)	+ + +	+ + +	+	+	+ + +
Flat (18)	+ + +	+ + + +	+	+	+ + +
Two-seam (0)	+	+	+ + +	+ + + +	+
Four-seam (0)	+	+	+ + +	+ + +	+ +
Four-seam (6)	+ +	+ +	+ +	+ +	+ +
Four-seam (12)	+ +	+ + +	+	+	+ + +
Four-seam (18)	+ + +	+ + +	+	+	+ + +
Western jib (0)	+ + +	+	+ + +	+ + + +	+ +
Tongue Trawls:					
Mongoose (0)	+ + +	+	+ + +	+ + + +	+ + +
Mongoose (6)	+ + + + +	+ + +	+ + +	+ + +	+ + + +
Mongoose (12)	+ + + + +	+ + + +	+ +	+ +	+ + + +
Mongoose (18)	+ + + + +	+ + + + +	+	+	+ + + + +
Three-wing (0)	+ + + + +	+	+ + + +	+ + + + +	+
Scorpion (0)	+ + +	+	+ + + +	+ + + + +	+ +
Scorpion (4)		+ +	+ + +	+ + + +	+ + +
Scorpion (6)		+ +	+ + +	+ + + +	+ +
Bib Net (6)	+ + +	+ + +	+ + +	+	+ +
Twin Trawl (0)	+ + +	+	+ + + + +	+ + + +	+ +

*Numbers in parentheses indicate number of floats.
All other nets constructed of #15 twine.

	Towing Tension (lbs)	Headrope Height (ft)	Net Spread (ft)	Spread Ratio (%)	Footrope Height (inches)
+	1350–1400	2.5–4.0	30.0–32.0	60–64	0
+ +	1450–1550	4.5–5.5	33.0–34.0	66–68	2.5–3.5
+ + +	1650–1800	6.5–8.5	37.0–39.0	74	4.0–5.0
+ + + +	1850–1950	10.0–11.0	41.0–42.5	76–78	6.0
+ + + + +	2000–2150	13.0	56.0	83–85	8.0

thereby, used less fuel (Figure 15). Therefore, a trawl with superior spread characteristics but high towing tension, such as the three-wing, can be built with light twine to reduce its towing tension to that of a two-seam balloon net. Although such a net would be cheaper to build and require less power to tow, it would be more vulnerable to damage when fished over snags, rough bottom, and mud (Figure 15).

Increasing door size from 6 ft by 36 inches to 9 ft by 40 inches increased net spread by 19% but also increased towing tension, and thereby, fuel consumption (Figure 16 and Table 9). Considerable detail regarding the effects of door size on net configuration was published by Watson *et al.* (1984).

An increase in towing speed, up to a point, essentially results in sweeping a larger amount of ground over a given time period (Figure 17). Sweeping more area may mean a larger yield, but at the cost of considerably greater fuel consumption. It is important to consider whether the shrimp are sufficiently abundant that the value of the additional shrimp harvested is greater than the cost of the additional fuel expended. At excessive towing speeds the gear may rise off the bottom and result in even less efficiency.

Increasing the length of the tow also results in sweeping a greater amount of bottom area. However, the increase in tow time beyond 3 hours usually results in poor quality shrimp, both because the shrimp are crushed by jellyfish, horseshoe crabs, and other large organisms and because dead shrimp deteriorate rapidly through microbiological decomposition. With the large amounts of cheaper pond-raised shrimp being imported into the U.S. and the huge increases anticipated in coming years, it is vital to the domestic shrimp industry to take all steps necessary to maximize product quality in order to remain competitive. Shortening the length of tow and immediately icing down the catch are two factors over which shrimp boat operators have direct control.

This study was not intended to identify the ideal trawl for the shrimp fishery; there is no such gear. It demonstrates the advantages and disadvantages with both the traditional types of shrimp trawls and the newer class of twin and tongue trawls. It provides the shrimp boat operator with information on how changes in rigging affect trawl performance, and it points out the need to improve the quality of the product landed at the dock. In the final analysis, the decision on what gear to use and how to rig it will depend on the captain's experience and assessment of many factors, including the species of shrimp, the type of bottom, currents, tides, and fuel costs.

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FIGURES

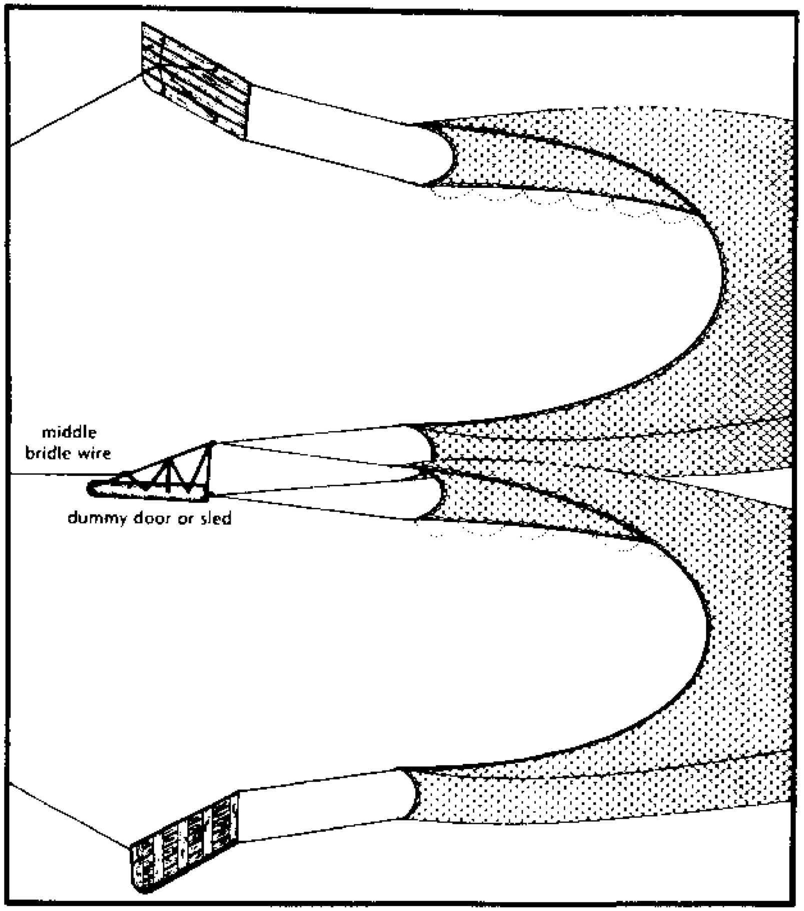


FIGURE 1 The Basic Twin-trawl System

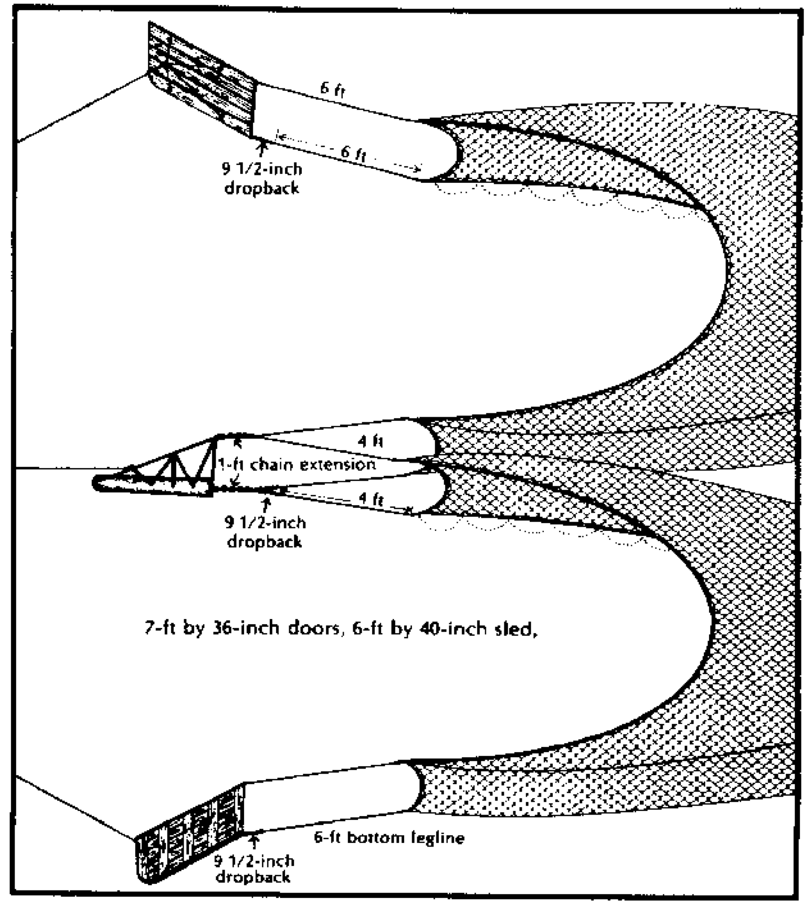


FIGURE 2A Twin 35-ft Flat Trawl System Used in Standard Tests

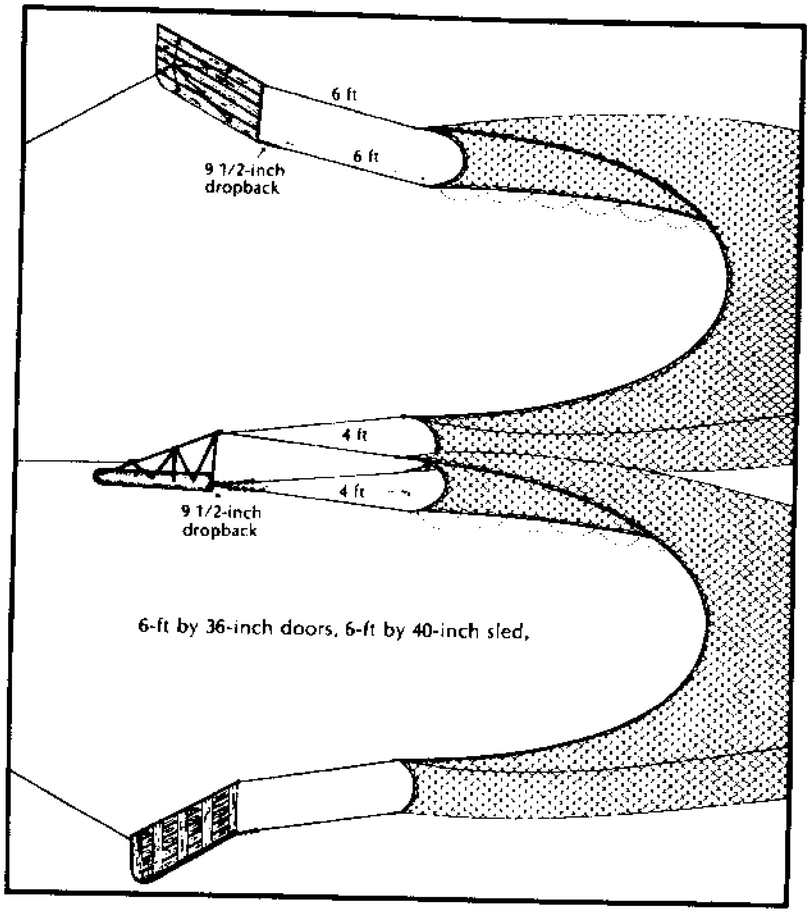


FIGURE 2B Twin 35-ft Flat Trawl System

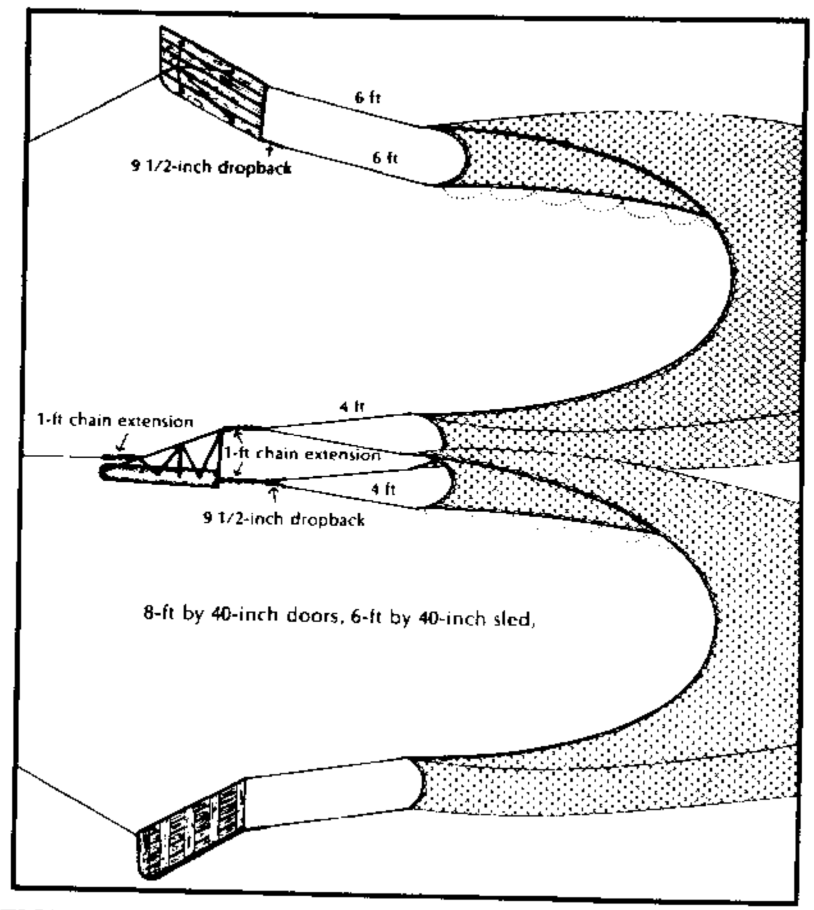


FIGURE 2C Twin 35-ft Flat Trawl System

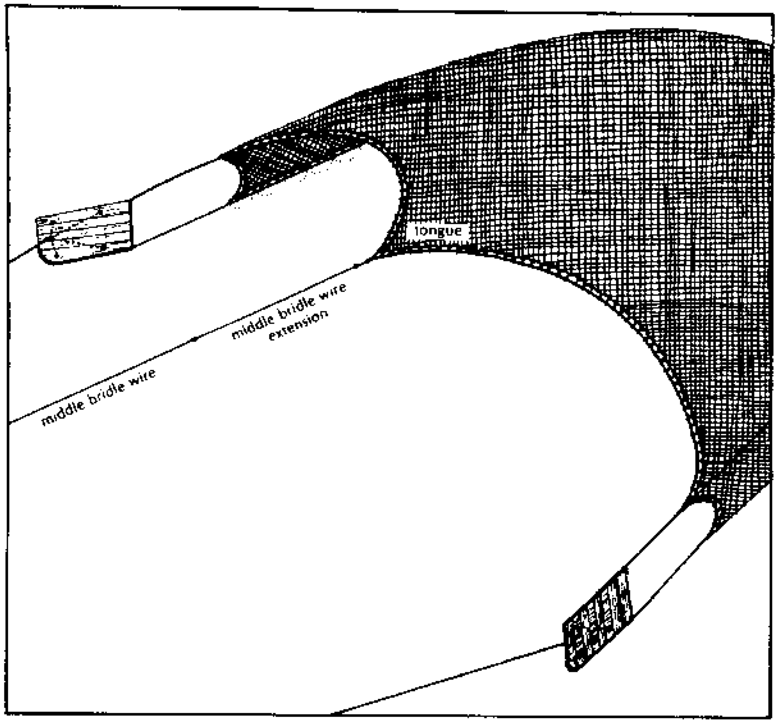


FIGURE 3 Basic Tongue Trawl System

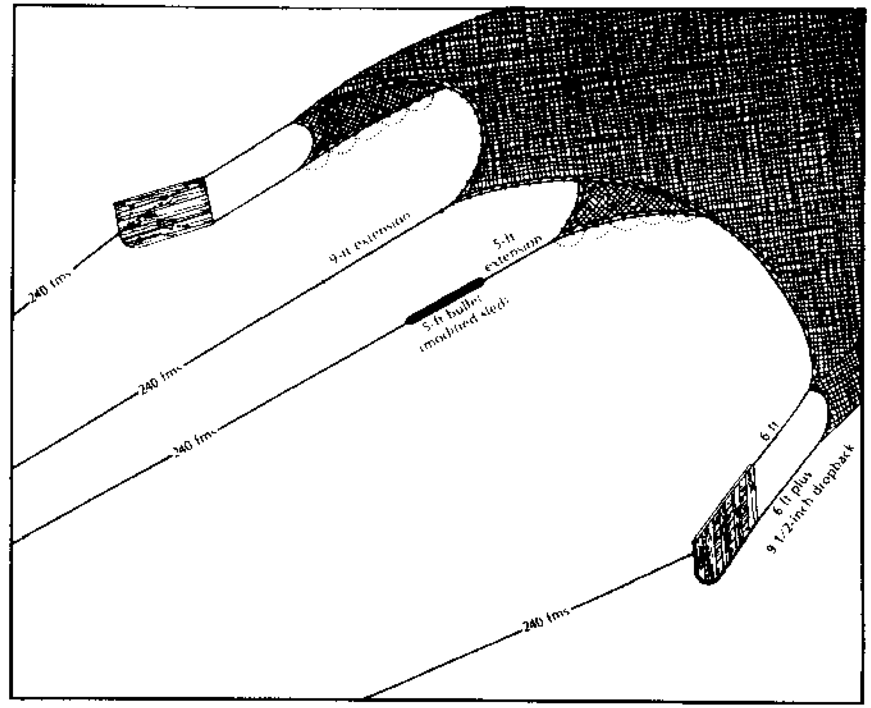


FIGURE 4 Three-wing Tongue Trawl System

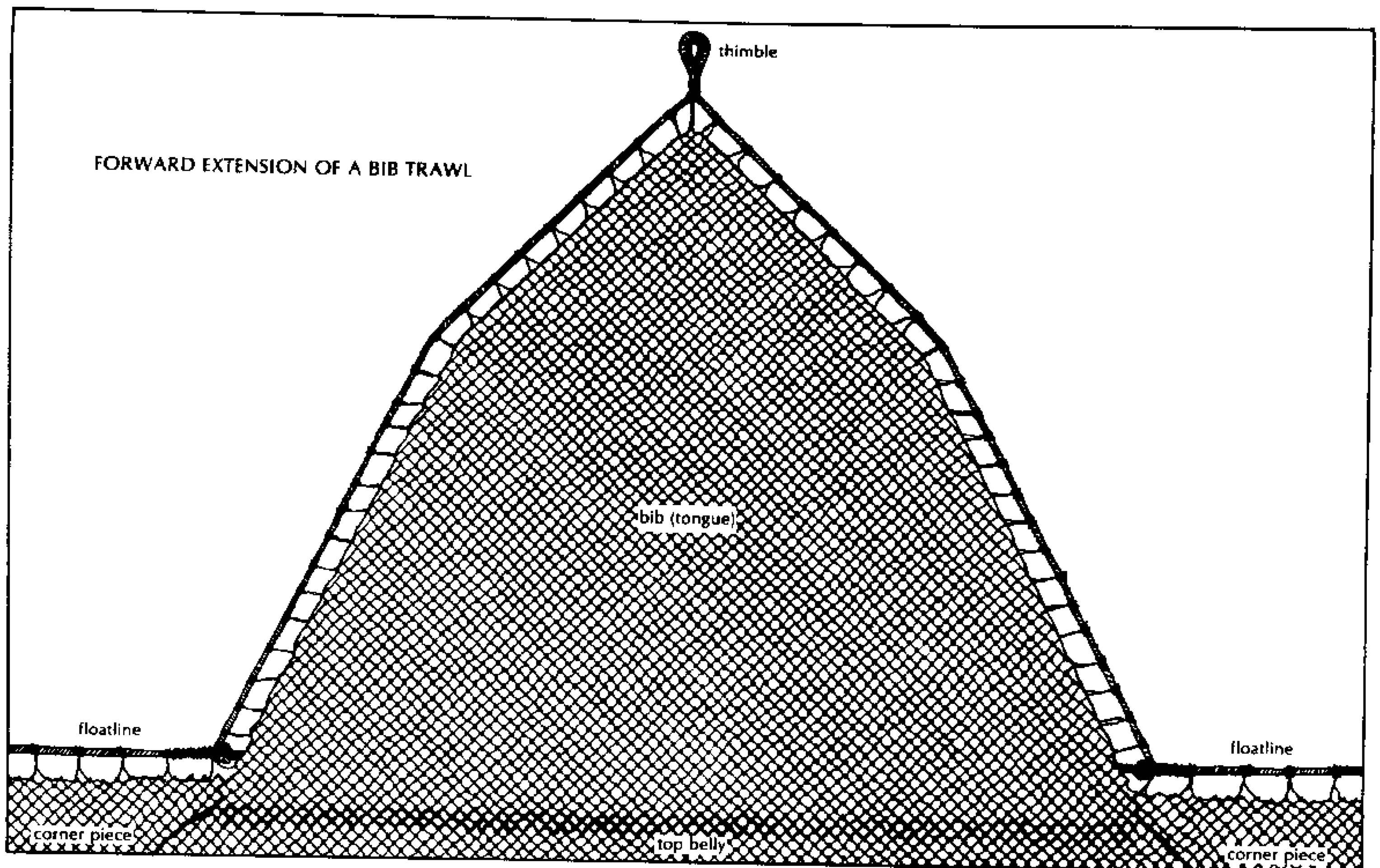


FIGURE 5 Bib Added to Conventional Trawl

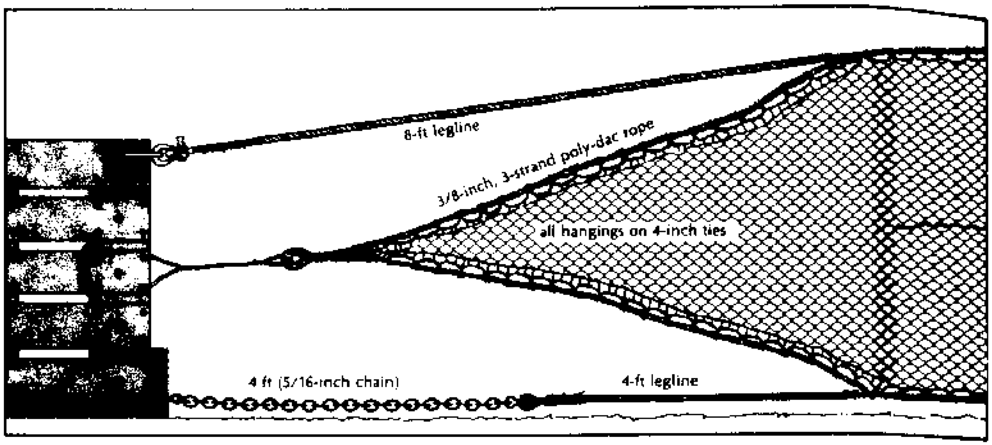


FIGURE 6 Wing Details on Spider Mongoose Trawl

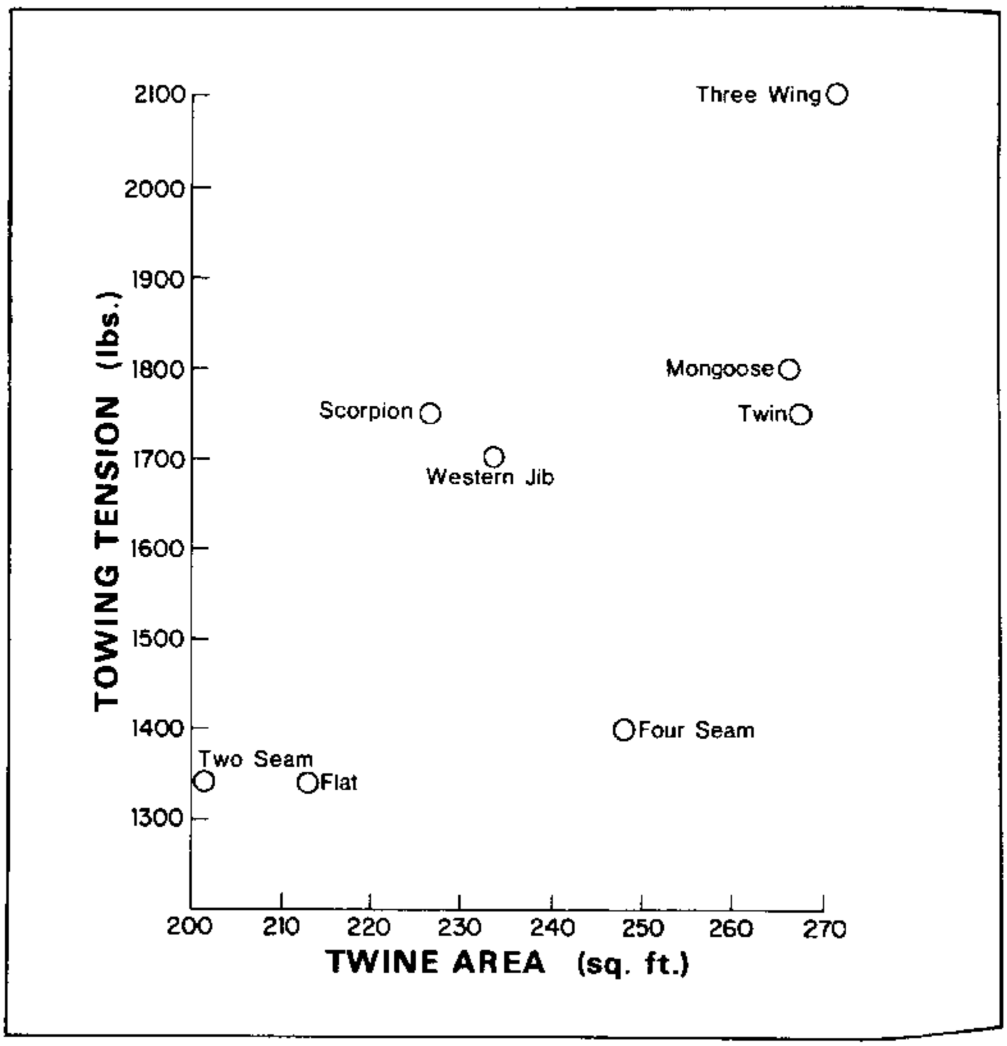


FIGURE 7 Relation Between Twine Area and Towing Tension

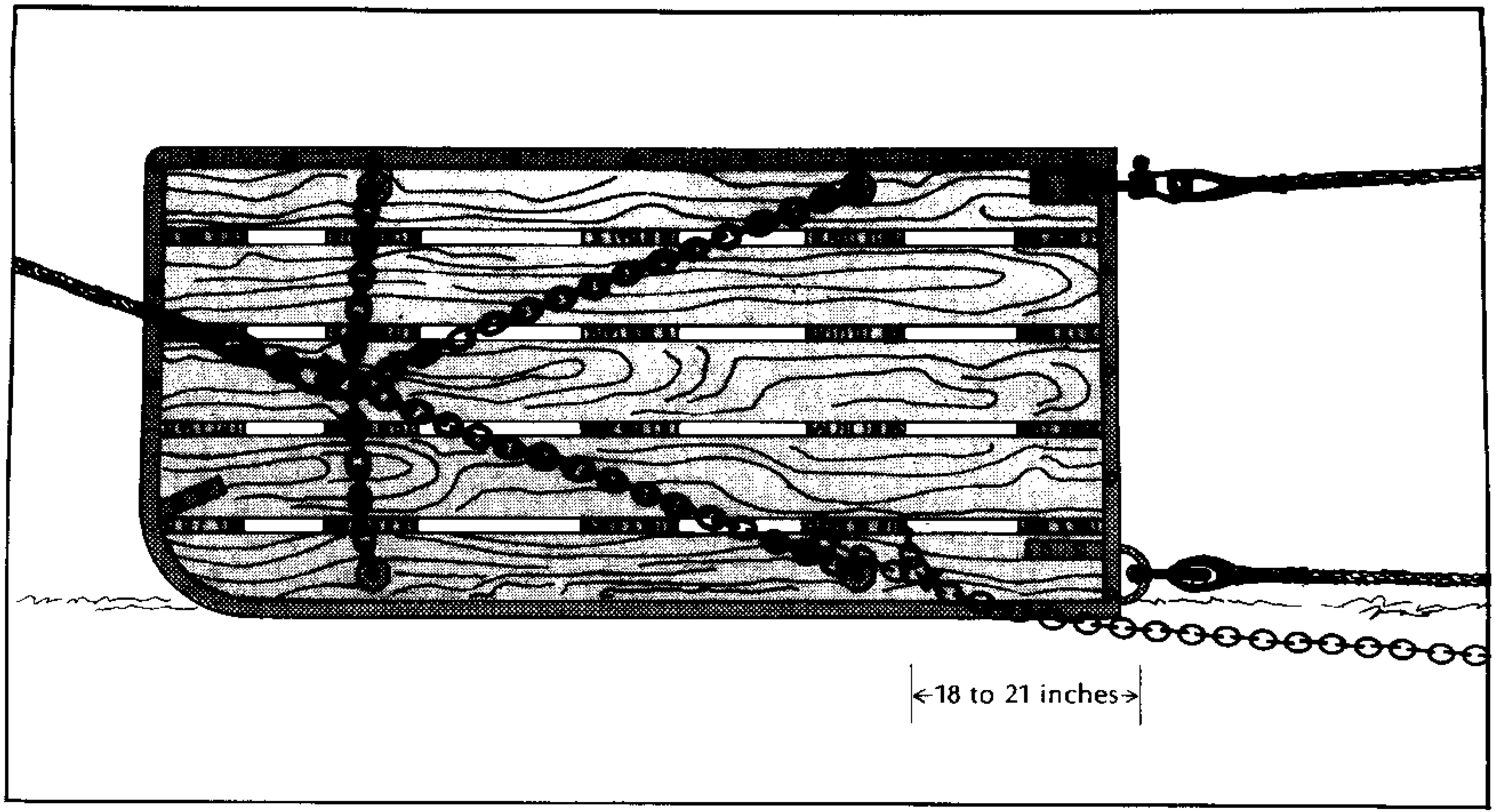


FIGURE 8 NMFS Tickler Chain Arrangement

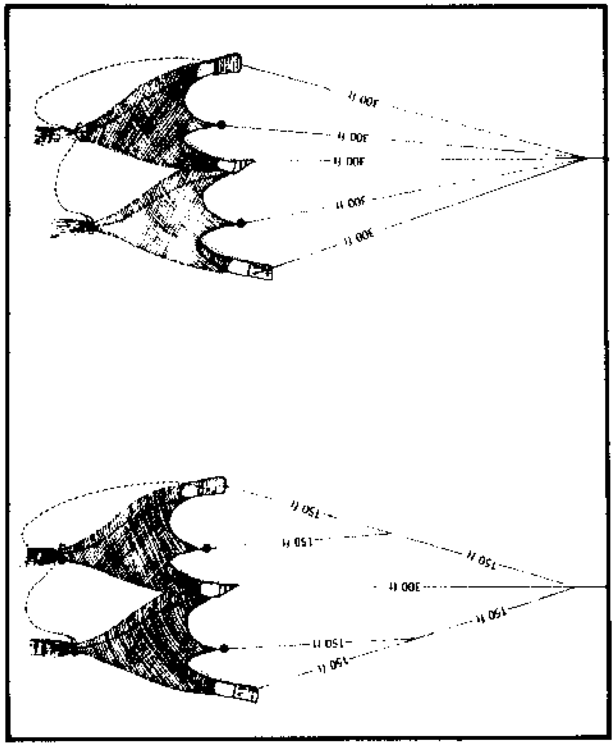


FIGURE 9 Twin-Tongue Trawl Systems with 3 + 2 Bridle (Top) and 5-wire Bridle (Bottom)

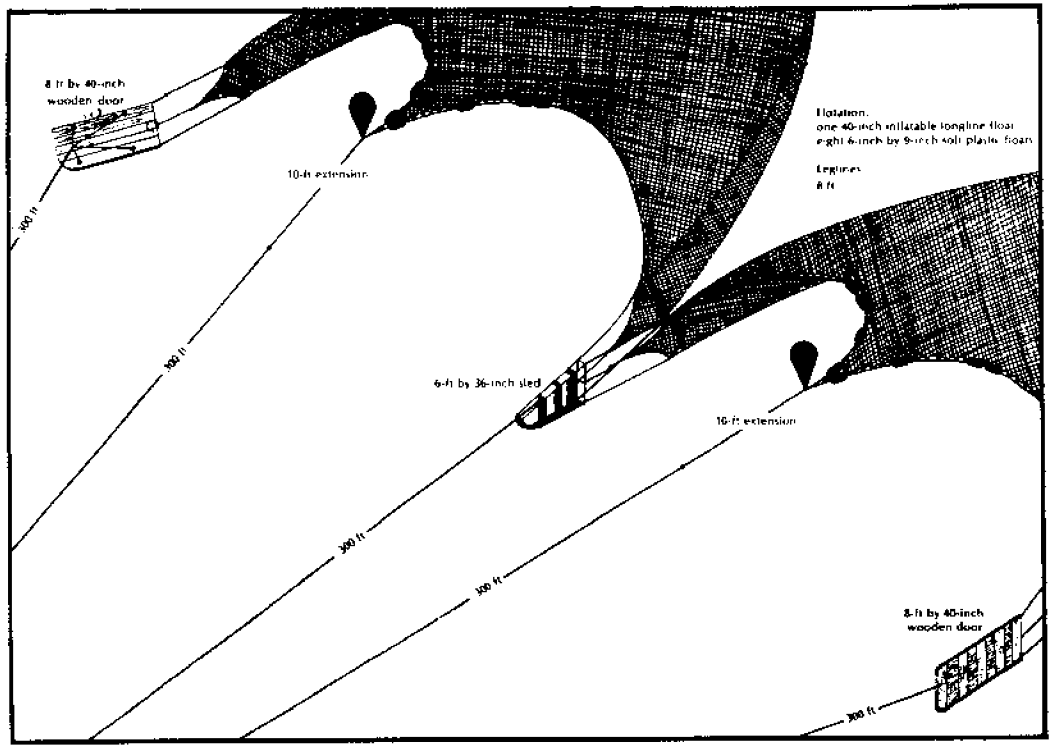


FIGURE 10 Burbank Twin 48-Ft Spider Mongoose Trawl

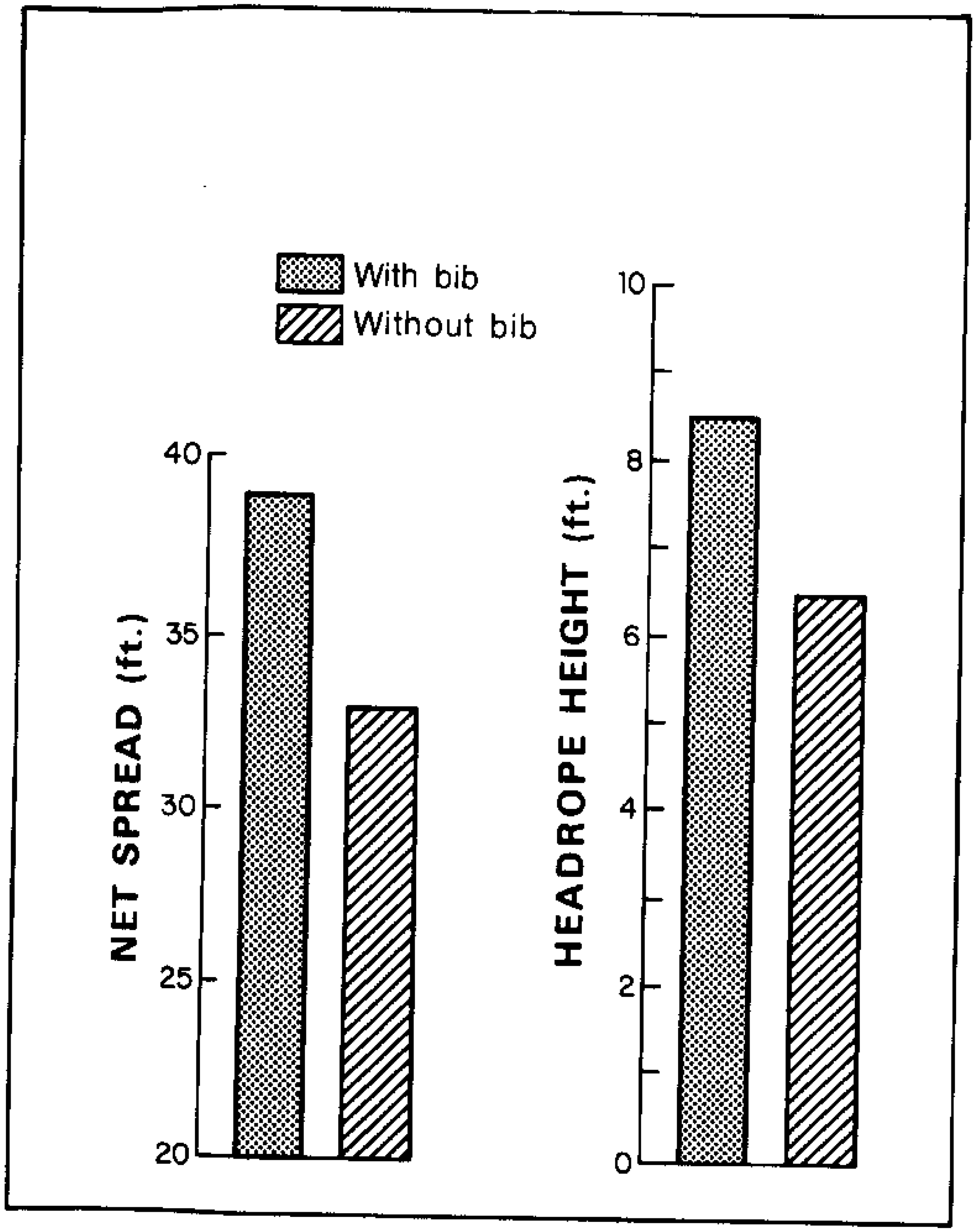


FIGURE 11 Performance of Flat Trawl With and Without Bib

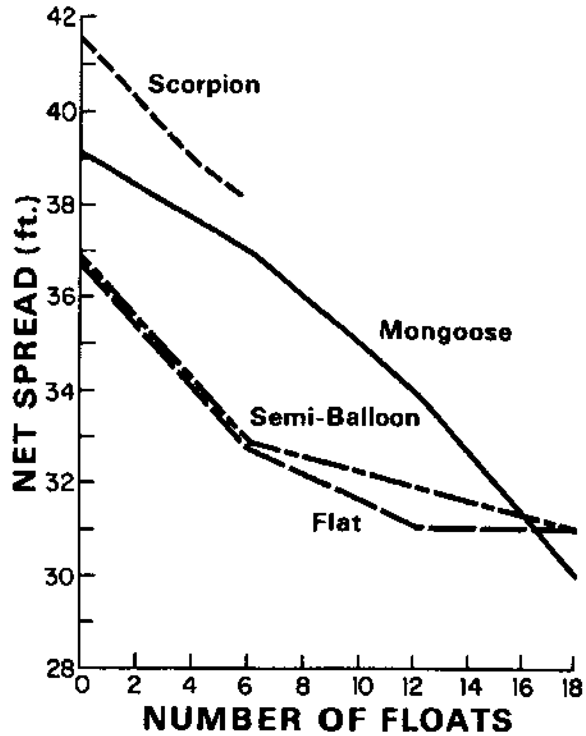


FIGURE 12 Effect of Flotation on Net Spread

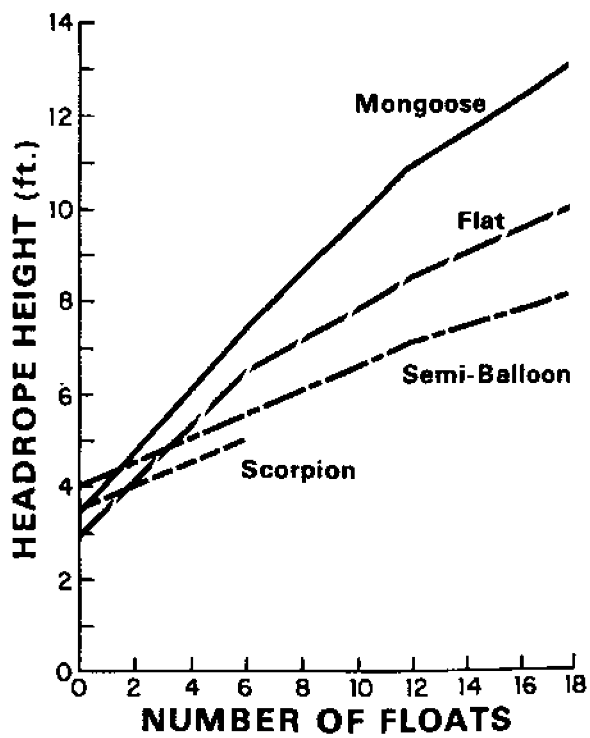


FIGURE 13 Effect of Flotation on Net Height

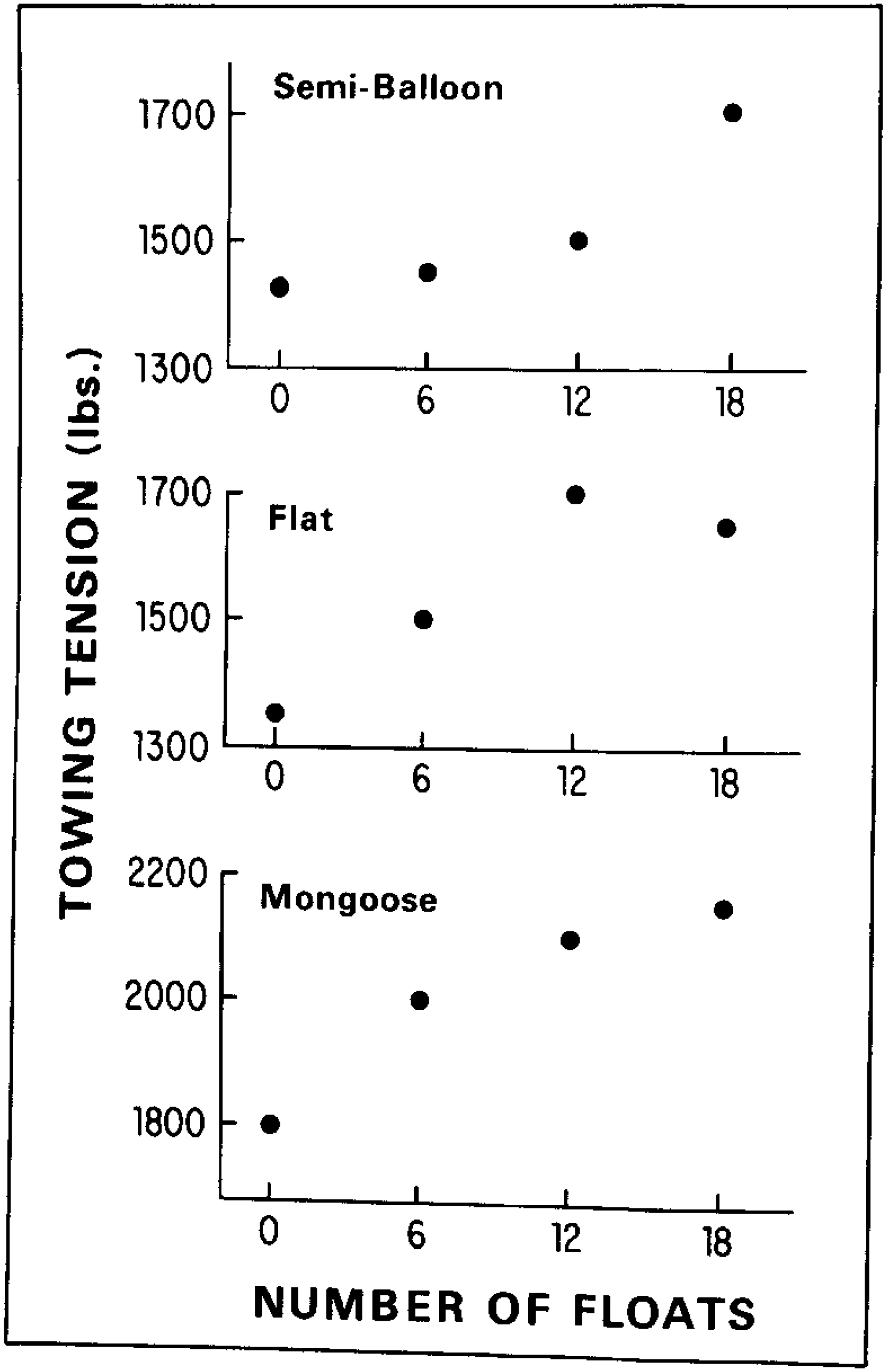


FIGURE 14 Effect of Flotation on Towing Tension

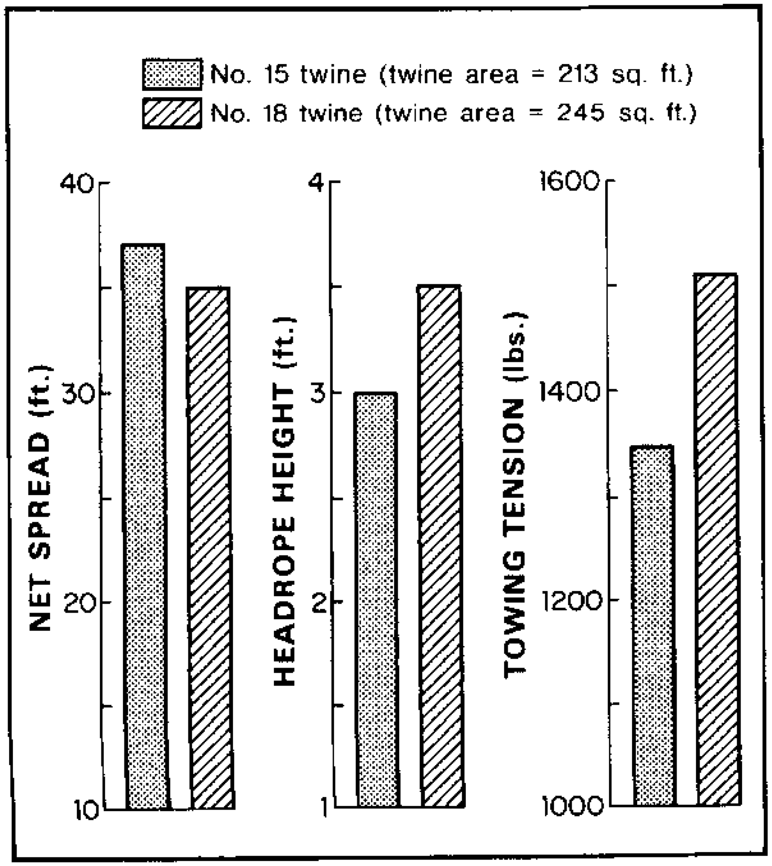


FIGURE 15 Effects of Twine Size on Net Spread, Headrope Height, and Towing Tension

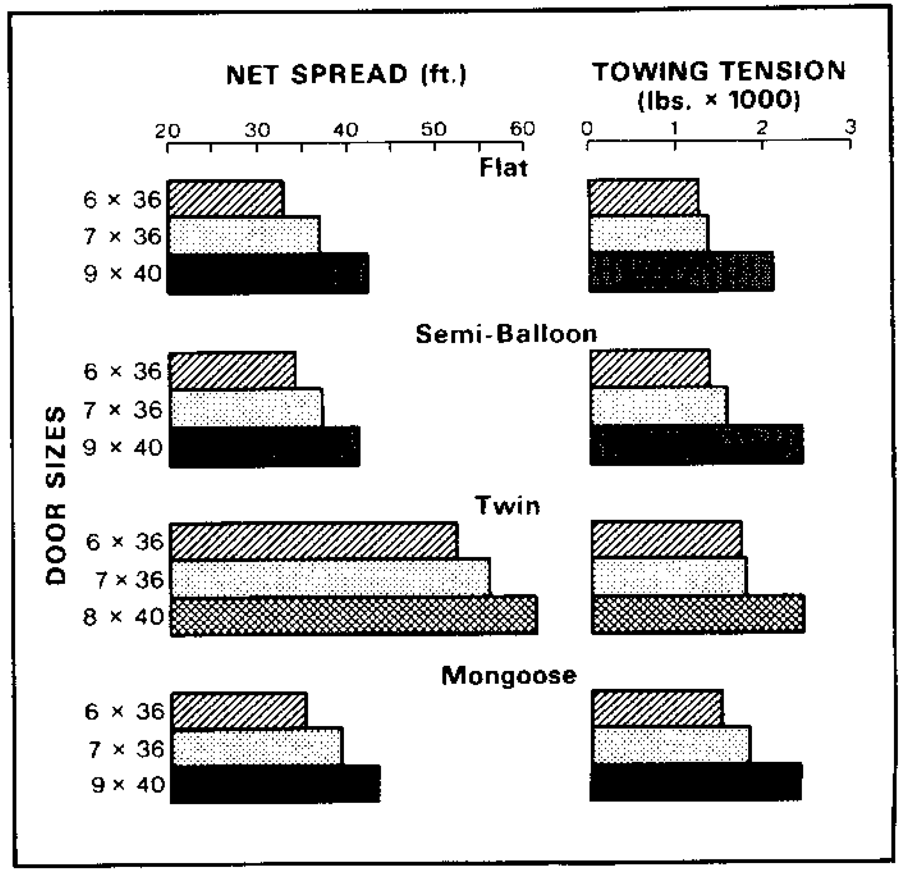


FIGURE 16 Effect of Door Size on Net Spread and Towing Tension

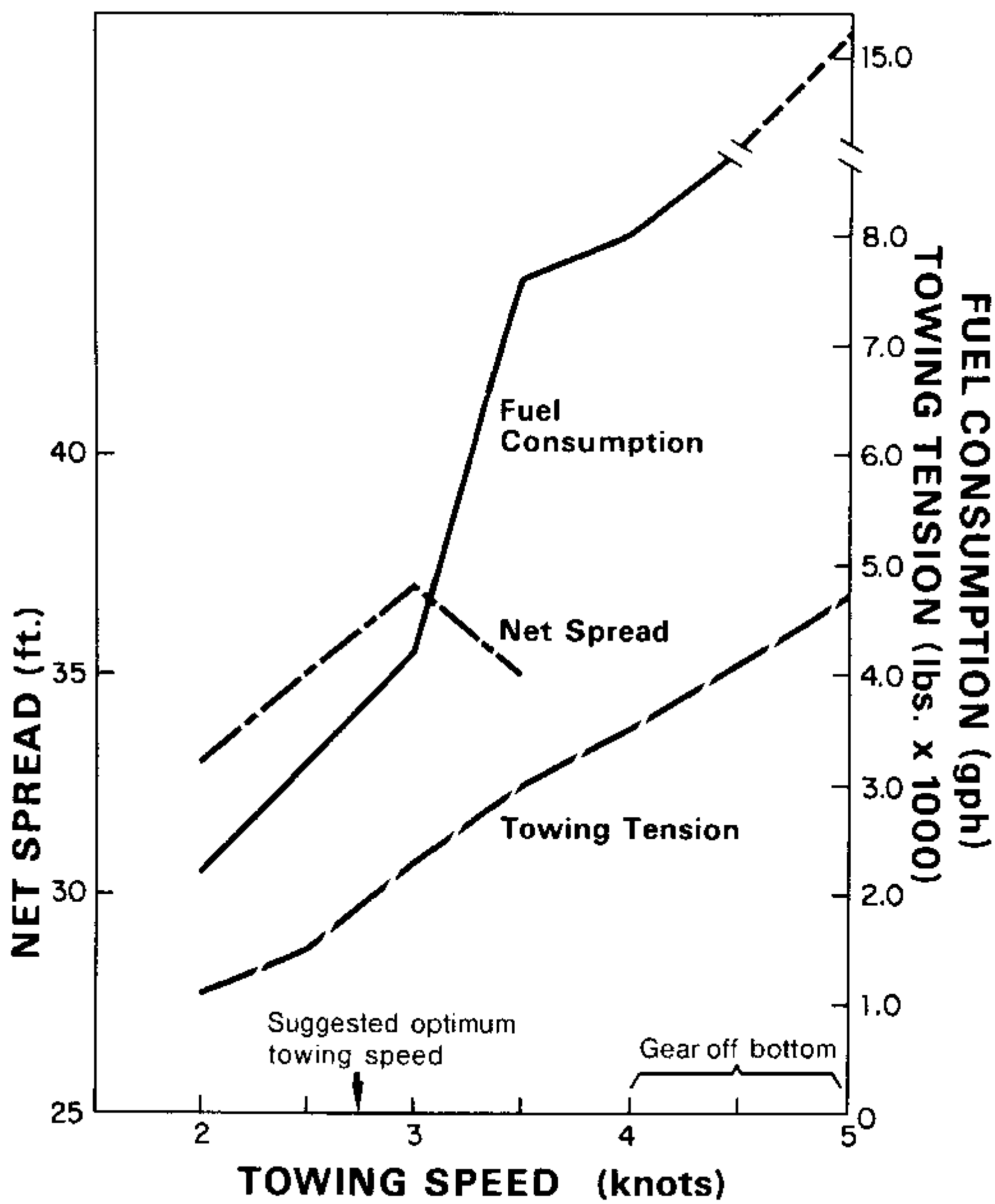
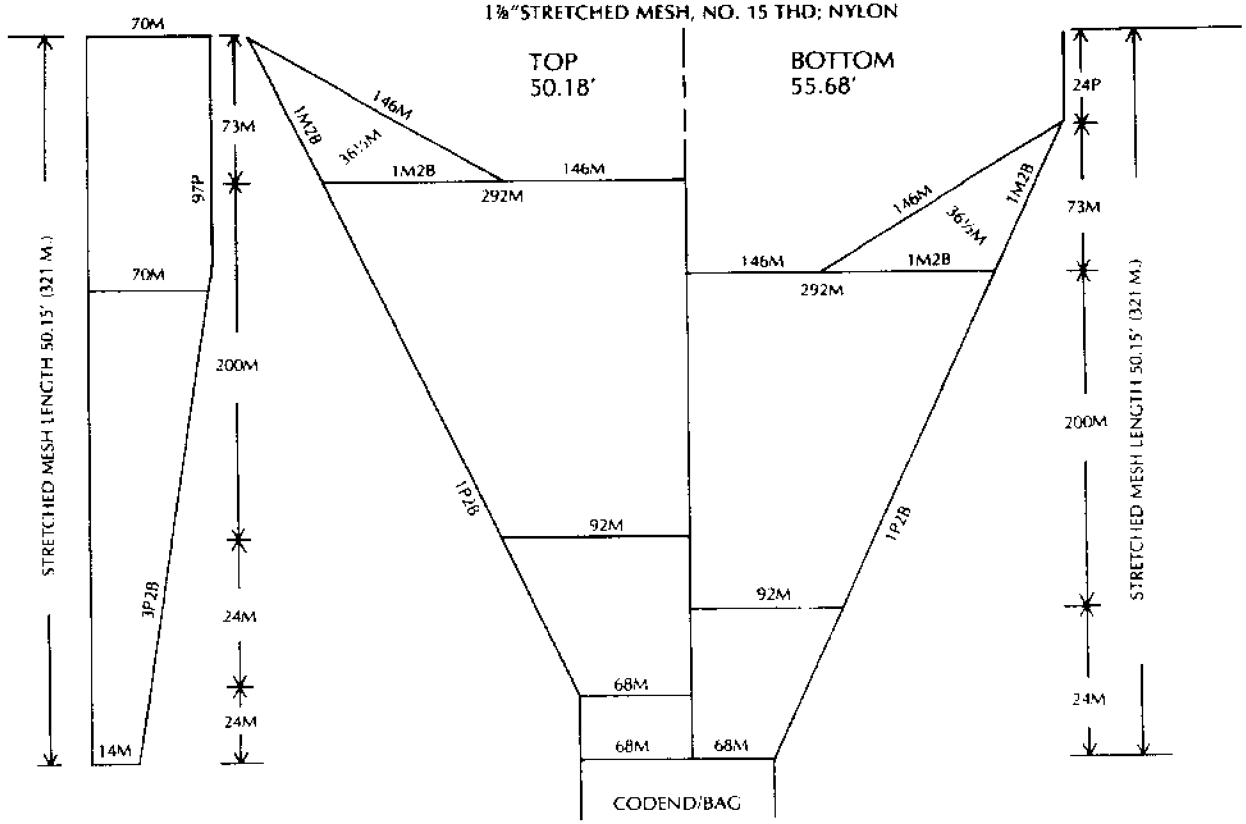


FIGURE 17 Effect of Towing Speed on Net Spread, Fuel Consumption, and Towing Tension

APPENDIX FIGURES

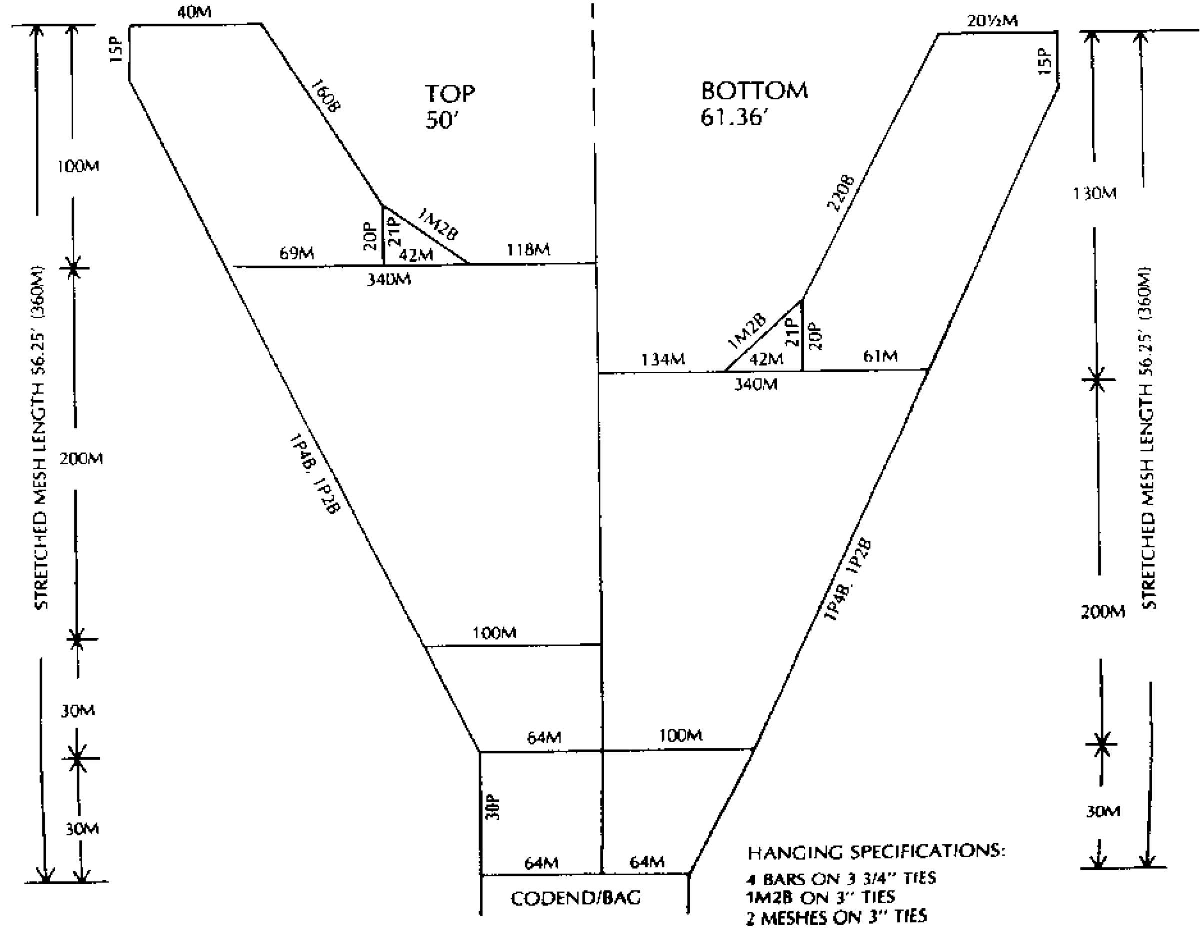
50' 4-SEAM FLAT SHRIMP TRAWL
1⅞"STRETCHED MESH, NO. 15 THD; NYLON



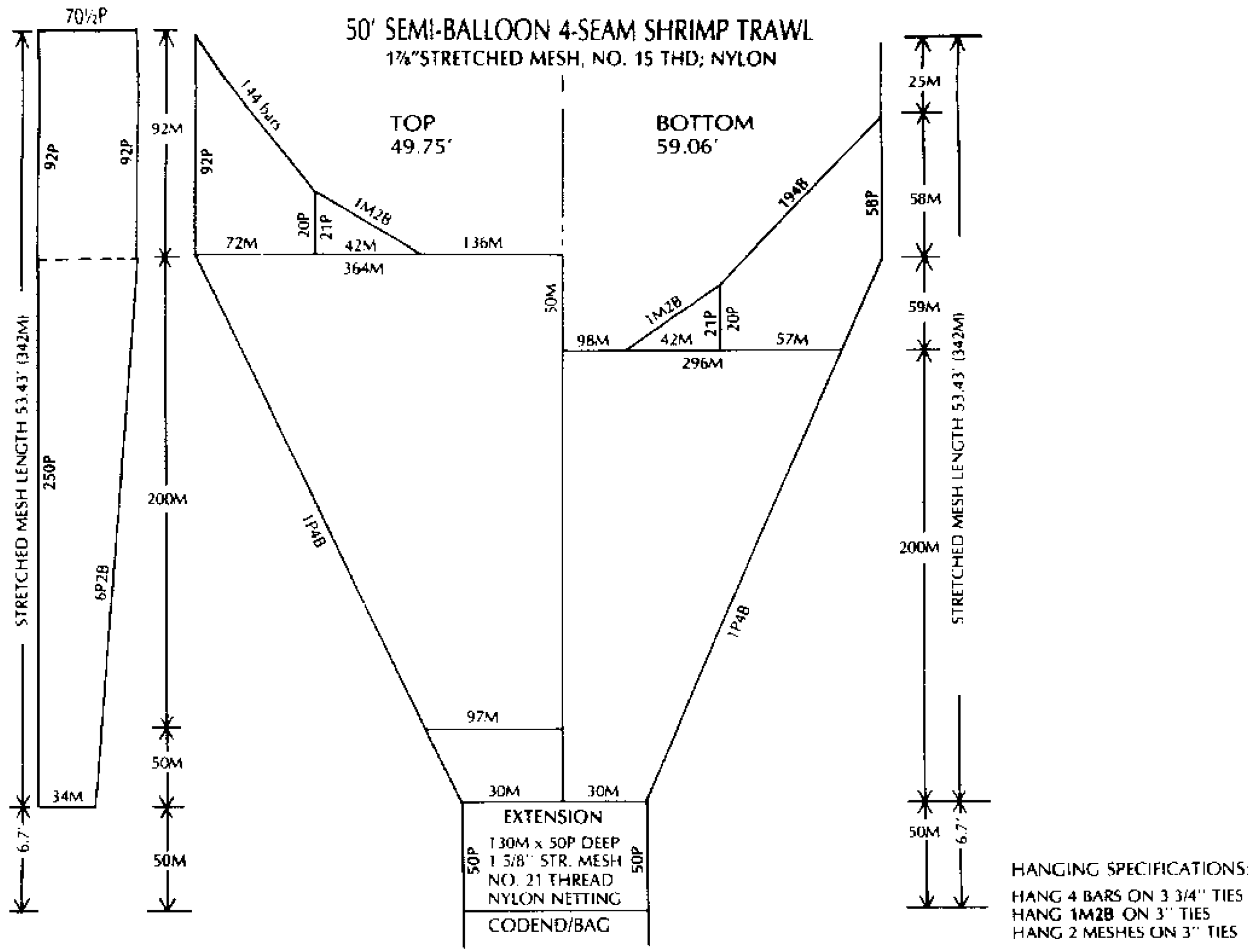
HANGING SPECIFICATIONS:
3 MESHES ON 4 1/8" TIES

APPENDIX FIGURE 1

50′ 2-SEAM BALLOON SHRIMP TRAWL
1⅞″STRETCHED MESH, NO. 15 THD; NYLON

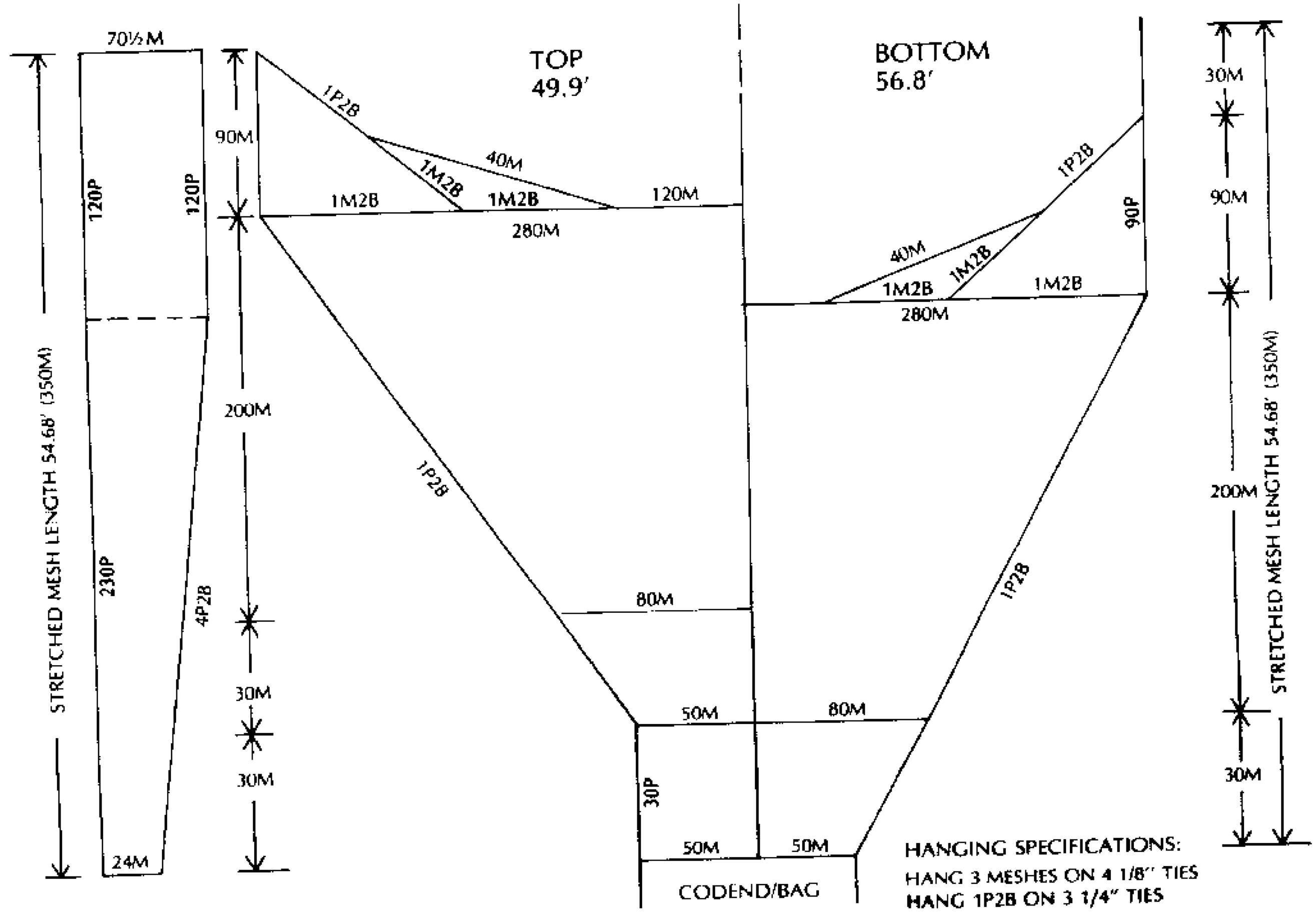


APPENDIX FIGURE 2



APPENDIX FIGURE 3

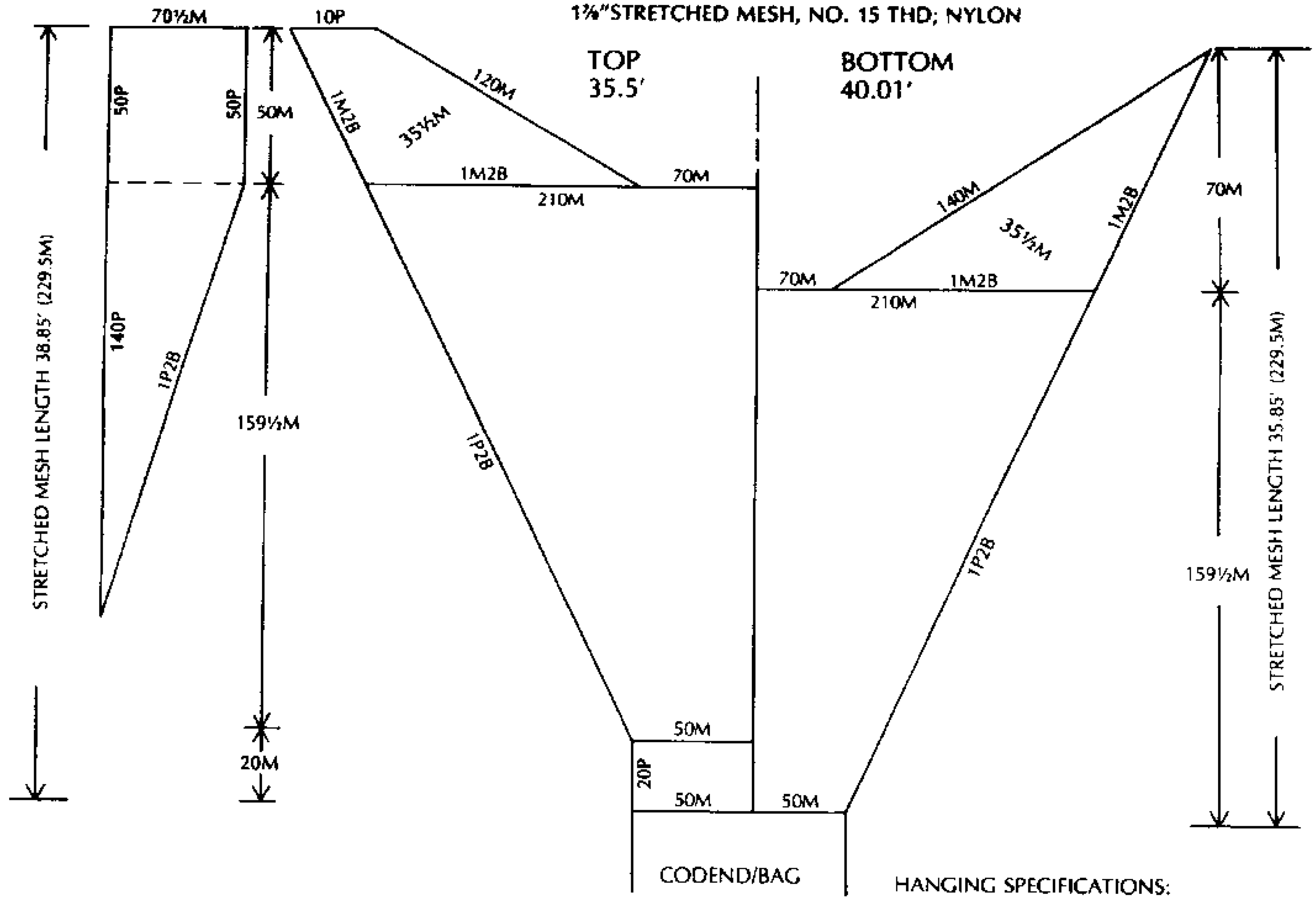
50′ WESTERN-JIB 4-SEAM SHRIMP TRAWL
1⅞″STRETCHED MESH, NO. 15 THD; NYLON



APPENDIX FIGURE 4

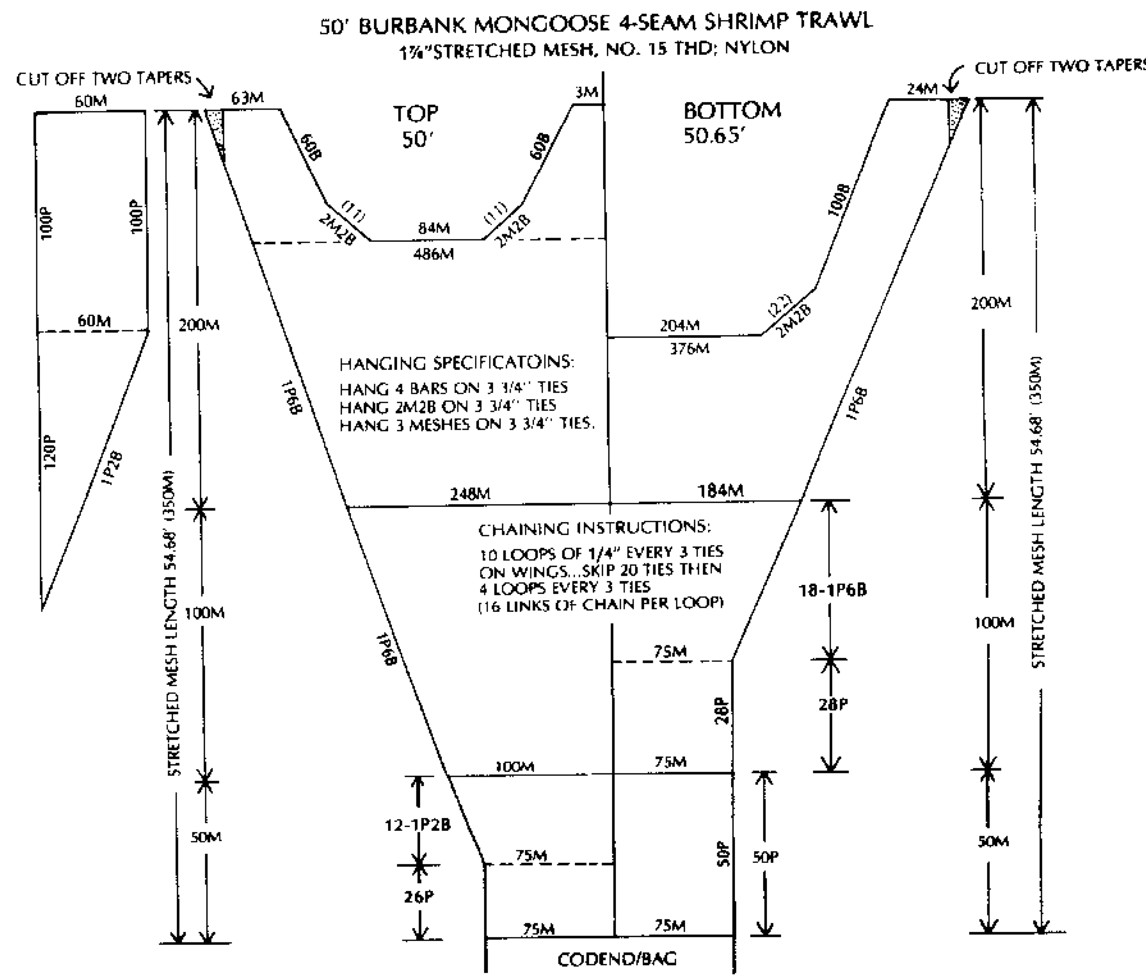
35' 4-SEAM TWIN FLAT SHRIMP TRAWL

1⅞"STRETCHED MESH, NO. 15 THD; NYLON



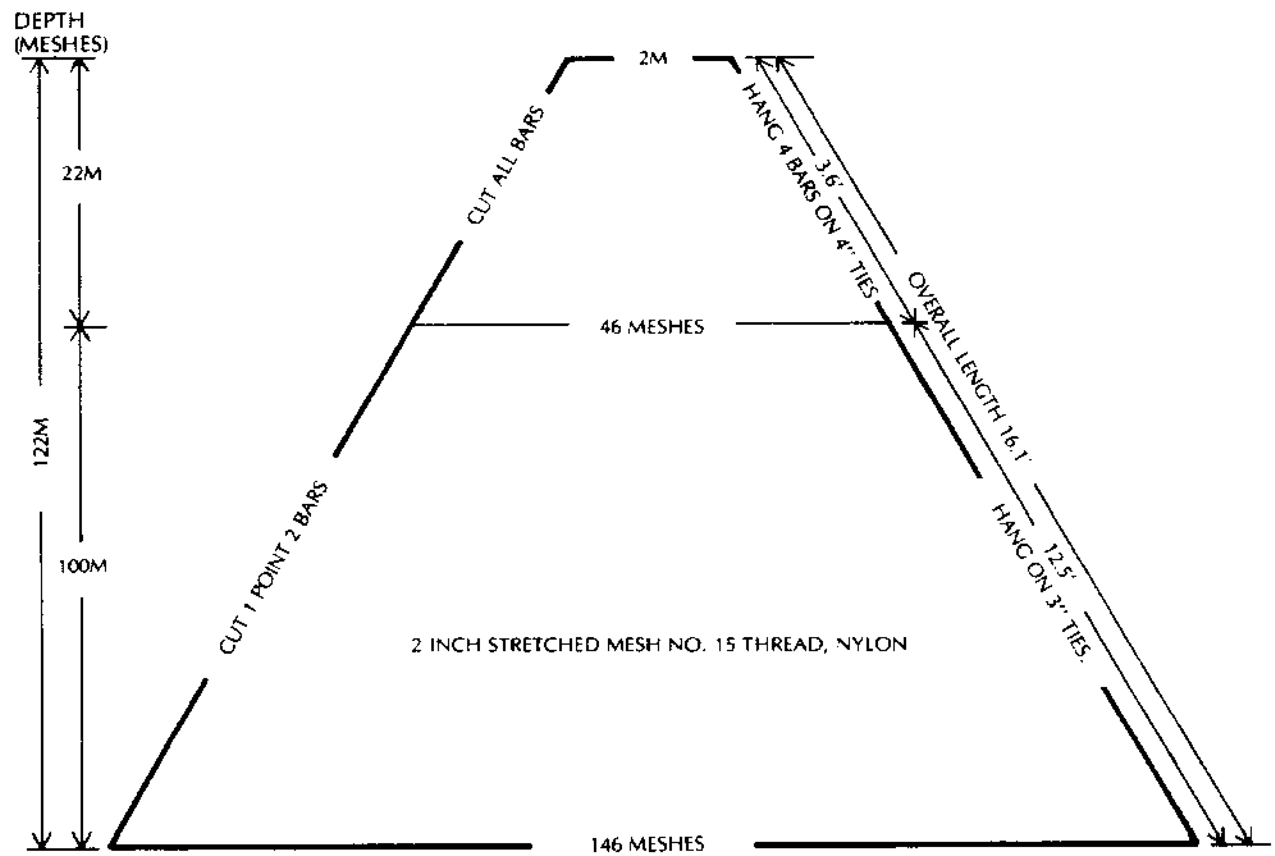
HANGING SPECIFICATIONS:
HANG 3 MESHES ON 4 1/8" TIES

APPENDIX FIGURE 5



APPENDIX FIGURE 6

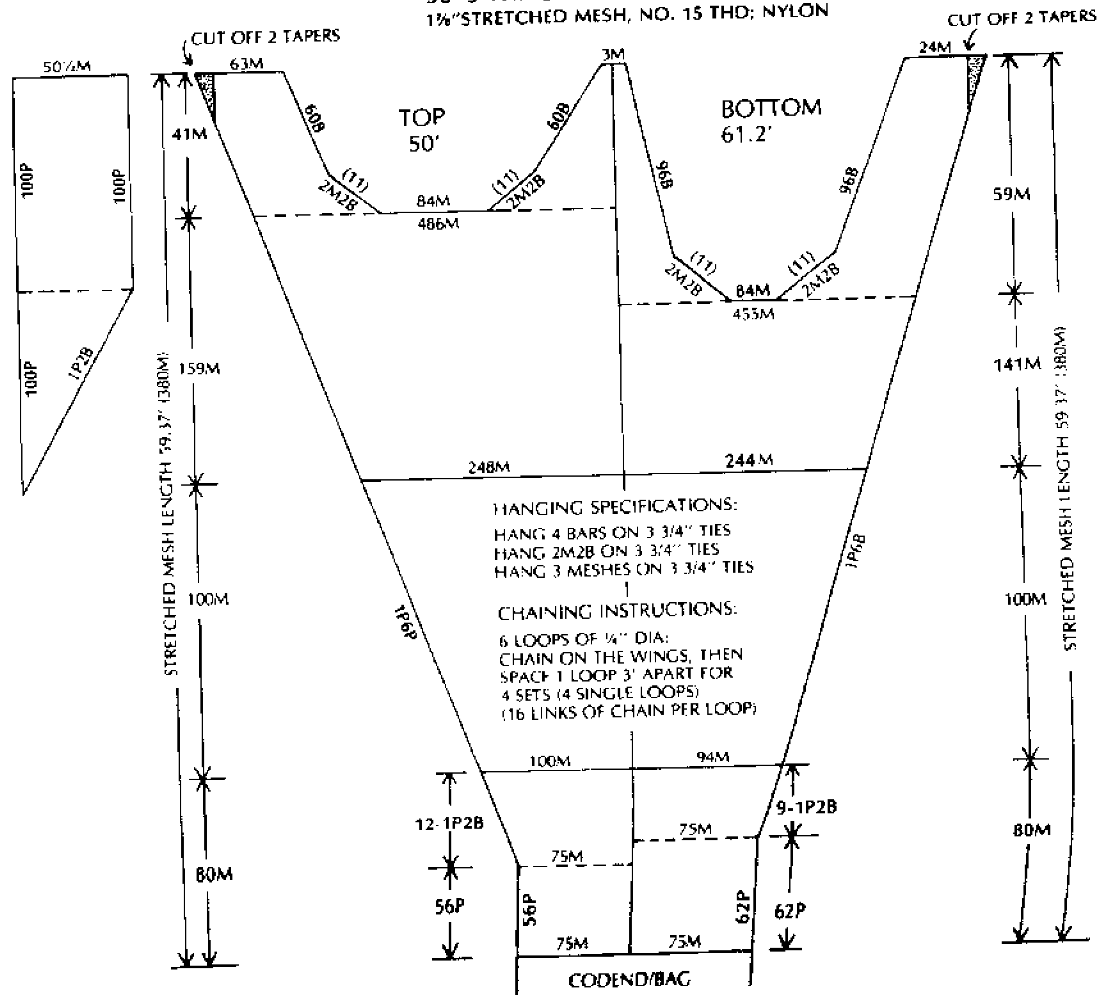
CUTTING DIAGRAM OF A BIB/TONGUE FOR A 50 FT. FLAT TRAWL



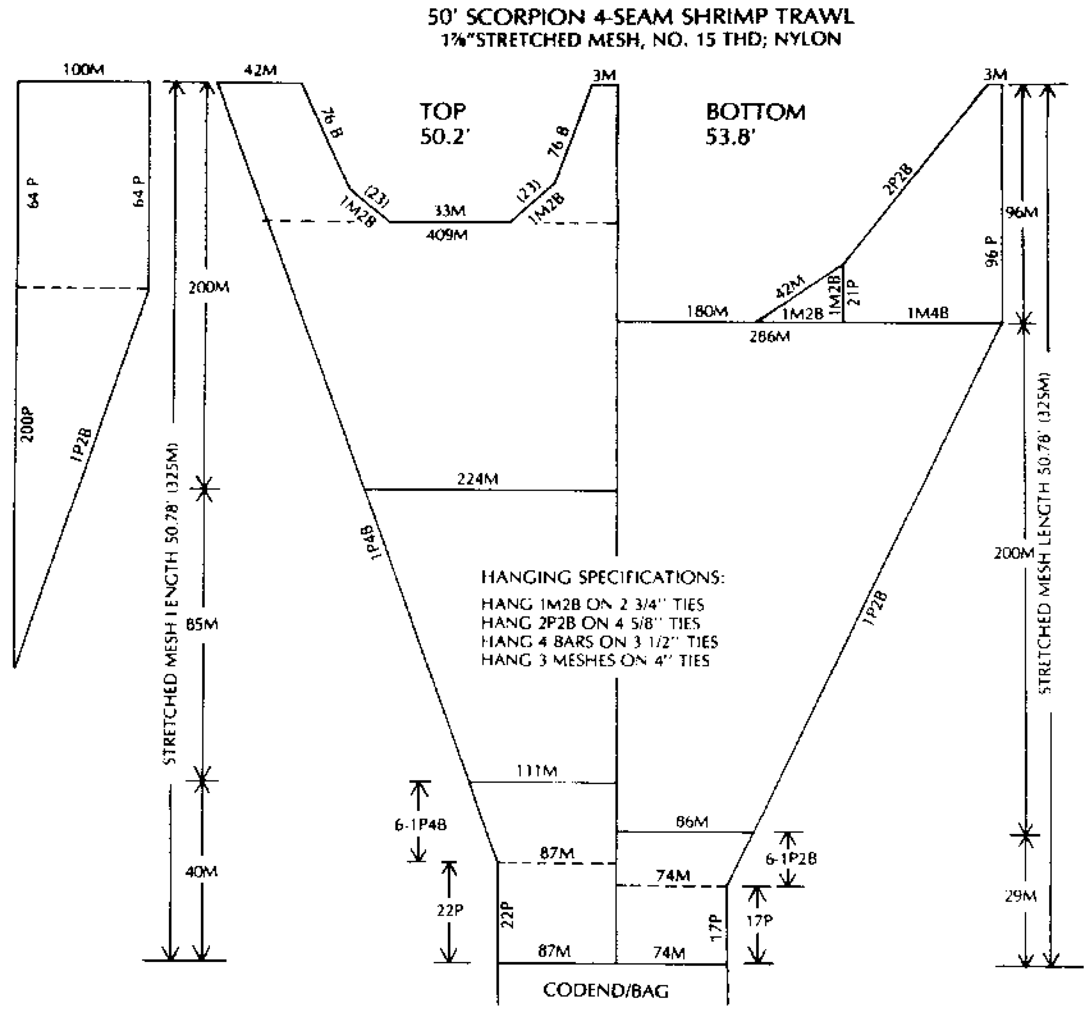
APPENDIX FIGURE 7

50' 3-WING 4-SEAM SHRIMP TRAWL

1⅞"STRETCHED MESH, NO. 15 THD; NYLON

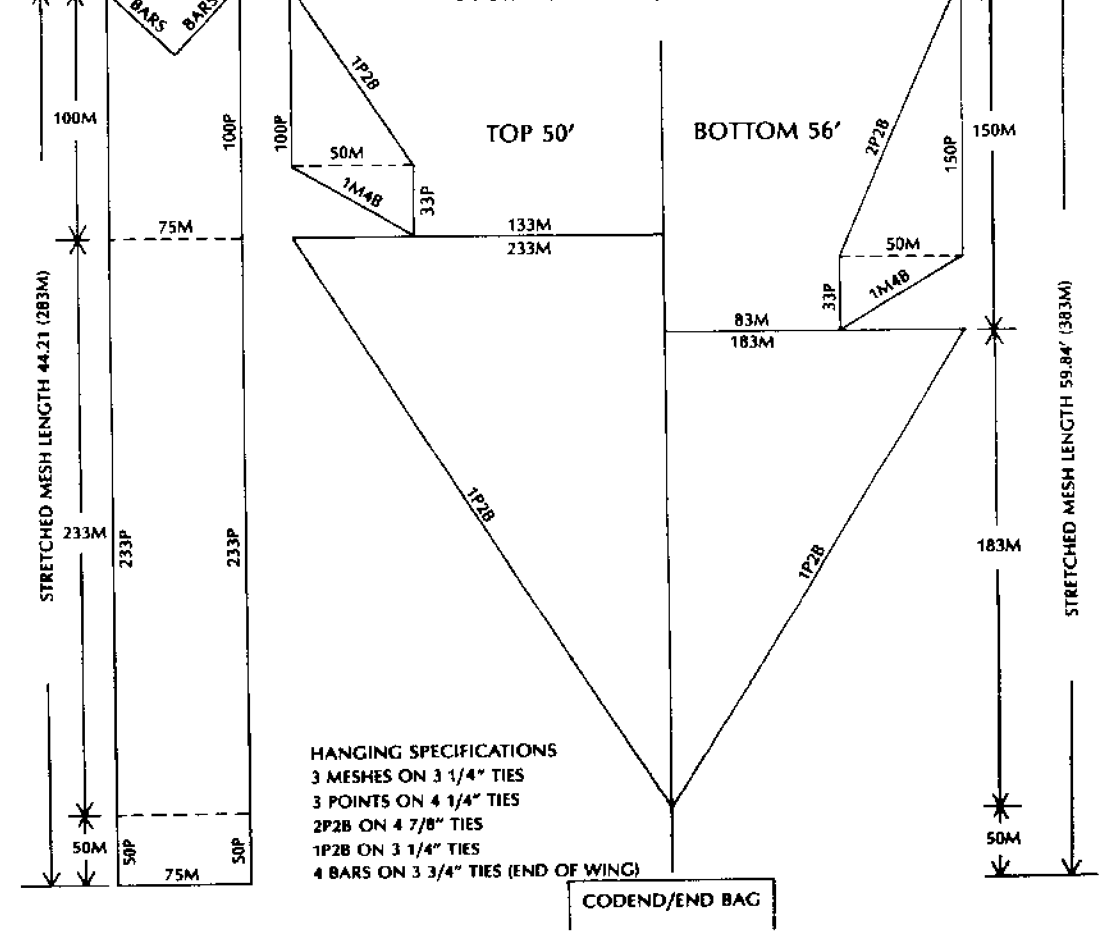


APPENDIX FIGURE 8



APPENDIX FIGURE 9

50′ 4-SEAM CAPTIVA SUPER X-3 SHRIMP TRAWL
1⅜″STRETCHED MESH, NO. 15 THD; NYLON



APPENDIX FIGURE 10