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NOAA Technical Report NMFS 3

Configurations and Relative Efficiencies of Shrimp Trawls Employed in Southeastern United States Waters

John W. Watson, Jr., Ian K. Workman,
Charles W. Taylor, and Anthony F. Serra

March 1984

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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Configurations and Relative Efficiencies of Shrimp Trawls Employed in Southeastern United States Waters

JOHN W. WATSON, JR., IAN K. WORKMAN, CHARLES W. TAYLOR, and ANTHONY F. SERRA[1]

ABSTRACT

Common shrimp trawl designs employed in the southeastern United States shrimp fishery are the flat, balloon, semiballoon, jib, and super X-3. Recent innovations in trawl design and rigging, including the twin trawl rigging and tongue trawl design, have improved the efficiency of shrimp trawling gear. A description of the construction techniques for the different designs indicate differences which affect gear performance. Measurements of horizontal spread and vertical opening for 76 trawl configurations indicate the relative efficiencies of the different designs. Maximum horizontal spreading efficiency was achieved by the "twin" and "tongue" trawl designs followed by the super X-3, jib, balloon, and semiballoon designs. Designs having the greatest vertical openings were the tongue and flat trawl designs followed by the semiballoon. Maximum total gape dimension was demonstrated by the "Mongoose" tongue trawl. Comparison of trawl spreading efficiency and door area to headrope length ratio indicates that a range of 70-80 in² (per door) of door area is required for each foot of trawl headrope length for maximum efficiency with conventional trawl designs and 60-75 in² per foot of headrope for tongue trawl designs.

INTRODUCTION

The penaeid shrimp fishing industry is one of the most valuable fisheries in the southeastern United States. A large trawler fleet operates in the Gulf of Mexico and off the southeastern coastal states from North Carolina to Texas. The three major species that make up the fishery are brown shrimp, *Penaeus aztecus*, white shrimp, *P. setiferus*, and pink shrimp, *P. duorarum*. Because the species vary in abundance both seasonally and geographically, the shrimp fleet is migratory.

The shrimp fleet consists of vessels of various designs and sizes which have undergone significant changes in recent years (Captiva 1966). Most trawlers tow at least two trawls, one from each side, and are called double-rig trawlers. Some smaller vessels tow a single trawl from the stern. Most vessels <55 ft in length fish in bays and sounds where the size and number of nets used are restricted by law. Larger vessels generally fish offshore and are not restricted to size or number of nets.

The demersal otter trawl is the primary fishing gear in the U.S. shrimp industry. It was first introduced in 1894 in Granton, Scotland, by a Mr. Scott who patented a bracketed, flat, wooden trawl used as a spreading device to replace the awkward beam on a beam trawl.

Shrimp trawling gear used by the southeastern U.S. shrimp fishery has been described by Bullis (1951), Juhl (1961), Fuss (1963 a,b), Marinovich and Whiteleather (1968), and Klima and Ford (1970). There is no complete description of current trawl construction designs and little information is available on comparative efficiencies of the different trawl designs or measurements of net spread and height with different rigging configurations.

For several years, the National Marine Fisheries Service conducted research on techniques to reduce the incidental take of sea turtles by shrimp trawls. This work presented a unique opportunity to compare numerous shrimp trawl designs and rigging configurations. Employing scuba diving techniques, scientists from the Harvesting Systems Branch, Mississippi Laboratories, Southeast Fisheries Center, measured over 100 trawl configurations. Results of this work, a comparative description of the gear types currently in use, discussion of relative efficiencies of different net designs, and the effects of various rigging configurations are presented.

COMPARATIVE DESCRIPTIONS OF SHRIMP TRAWLING GEAR

A fundamental knowledge of net design and terminology is assumed. Definitions of trawl terminology and explanations of webbing tapers and trawl construction are available from several publications (Bullis 1951; Motte 1972; Gutherz et al. 1974).

Otter Trawl

The basic components of an otter trawl are shown in Figure 1. The trawl body (A) is the principal section of webbing from which the trawl is formed. The jibs or corners (B) are triangular pieces of webbing attached to the wing along the forward edge of the body. The jib assists in giving the trawl overhang, relieves excessive tension between the trawl body and wing, and forms a uniform shape in the trawl mouth. The wings (C) are the sides of the trawl separating the top body from the bottom body. The cod end (D) is a tubular-shaped piece of webbing attached to the body which holds the catch of the otter net. These basic components are cut and assembled in different ways to form the various trawl designs.

Historically, the most popular trawls in the southeastern U.S. shrimp fishery have been the flat trawl, the balloon or two-seam trawl, the semiballoon or four-seam trawl, and more recently the jib and the super X-3 trawl.

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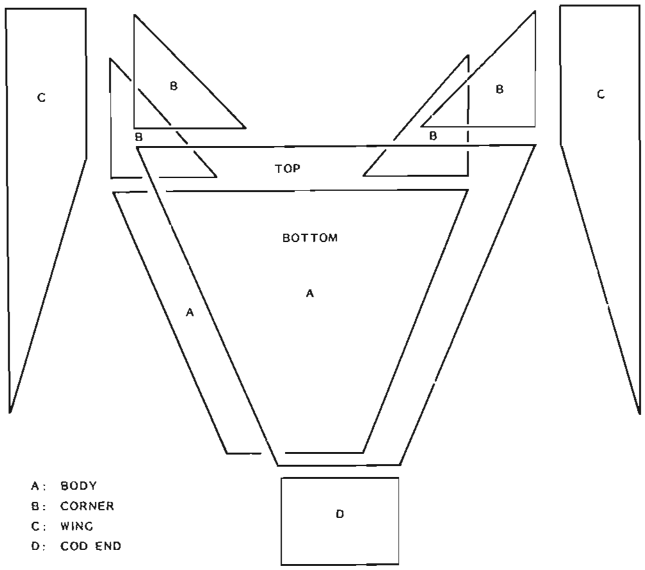

Figure 1.—Basic components of the otter type shrimp trawl.

Flat Trawl

The flat trawl (Fig. 2) consists of four webbing panels: Top and bottom body panels, and wings. The distinguishing characteristic of the flat trawl is the construction of the corner pieces which are cut in a one-point, two-bar taper called a jib cut to form a 120°-30°-30° triangle. The long side of the corner is the hanging edge; the tapered edges are sewn to the body and wing. This method of construction allows the towing strain to be transferred along the bars of the webbing. The entire hanging edge of the top and bottom panels, including the corners, consists of meshes. The amount of webbing sewn to a given length of headrope or footrope is determined by how tightly the webbing is hung. To provide setback (the distance the footrope pulls behind the headrope), the leading edge of the bottom body panel is attached to the wing behind the line of attachment of the top body panel. To allow for the setback, the number of meshes in the setback are cut from the rear of the bottom body panel, or extra meshes can be added between the top panel and the cod end.

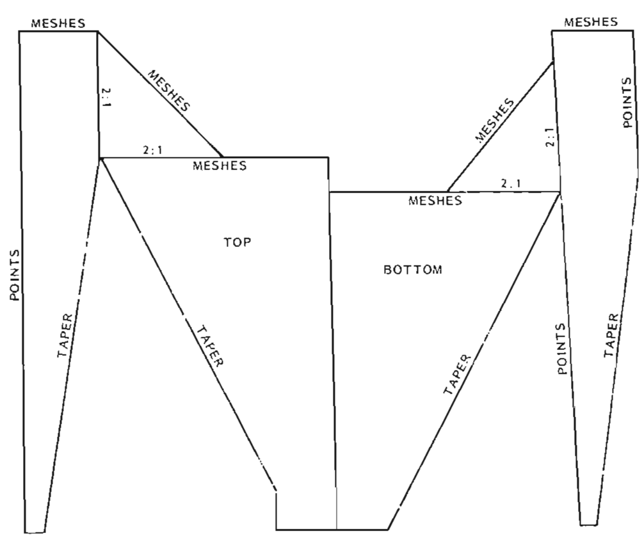

Figure 2.—Flat trawl generalized schematic.

Balloon Trawl

The balloon or two-seam trawl (Fig. 3) is constructed from two body sections only; the top and bottom sections are joined directly to each other forming a two-seam net. The body sections consist of three parts: The main body and two corner pieces. The balloon trawl is characterized by its two-seam design, its corner piece construction, and method of hanging. Hanging edges of the balloon trawl differ from those of the flat trawl in that the body section is all meshes and the corner pieces are all bars. The outside edges of the corner piece and the body section both have the same taper. Hanging ratios of the balloon trawl also differ from those of the flat trawl in that the corner piece is generally hung tighter (up to 100%) than the body (70%). Setback is achieved in the balloon trawl by attaching the front of the bottom body panel several meshes behind the front of the top body panel. The bottom corner pieces are larger than the top corner pieces to allow for the setback.

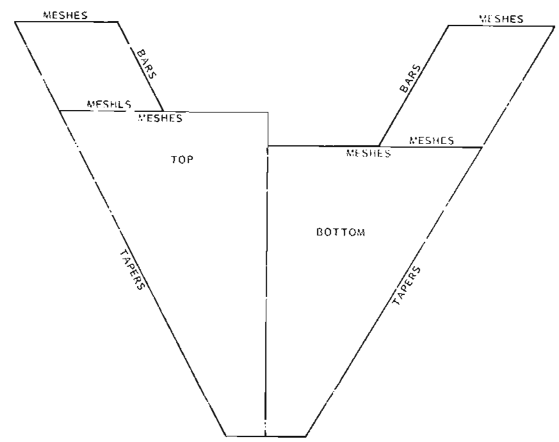

Figure 3.—Balloon trawl generalized schematic.

Semiballoon Trawl

The semiballoon trawl (Fig. 4) has characteristics of both the flat and balloon trawl designs. It has wings and a four-seam body design similar to the flat trawl, but the corner pieces and the hanging characteristics resemble those of the balloon trawl. The corner pieces of the semiballoon trawl are cut to the shape of a right triangle with the hanging edge equal in stretched mesh length to each of the sewing edges. The corner piece of the semiballoon trawl has an all-bar hanging edge, all-mesh-body sewing edge, and all-point-wing sewing edge. For added strength in the corner, most trawl manufacturers add a second small corner to the intersection of the body and corner. The small corner is tapered two-meshes and one-bar, or two-meshes and two-bars, on the hanging edge and all meshes on the sewing edges. The semiballoon is hung in the same manner as the balloon trawl, and setback is achieved by the same methods described for the flat trawl.

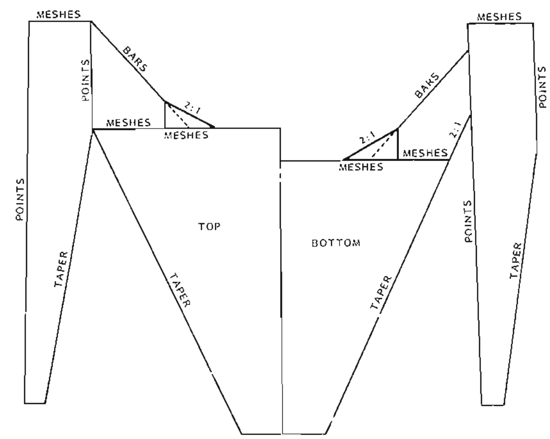

Figure 4.—Semiballoon trawl generalized schematic.

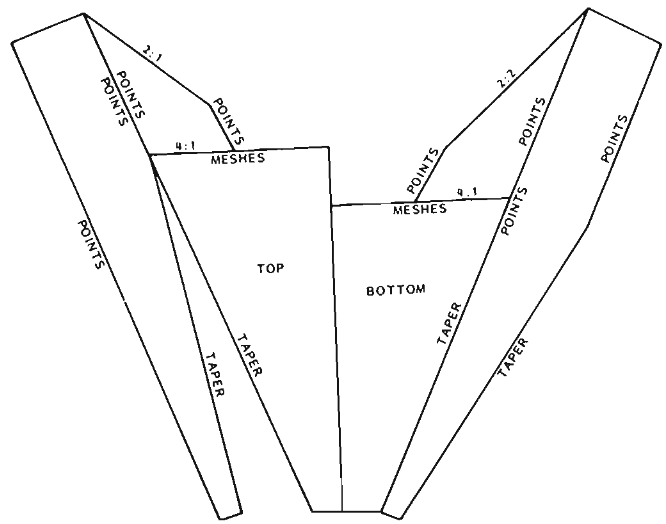

Figure 6.—Super X-3 generalized schematic.

Jib Trawl

The jib trawl or western jib (Fig. 5) is similar to the flat trawl in construction, but differs from the flat and other trawls in the construction of the corner pieces or jibs. The long side of the corner is the hanging edge and is jib cut. The sewing edge of the corner attached to the body panel is tapered one-mesh and two-bars. This taper shifts the wing outward, giving the trawl a greater horizontal spread. The wing sewing edge of the corner is cut on all points, allowing the webbing in the corner pieces to pull in the same direction as the wing for less webbing distortion. Setback is provided by attaching the bottom body panel to the wing in the same manner as the flat trawl.

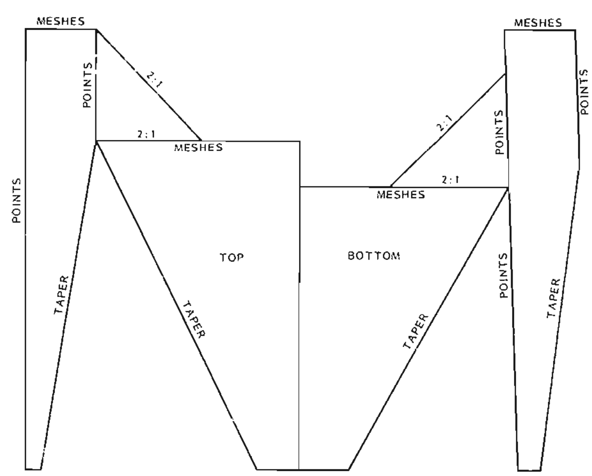

Figure 5.—Jib trawl generalized schematic.

Super X-3 Trawl

The super X-3 trawl is very similar to the jib trawl except in the corner piece design (Fig. 6). The long side (hanging edge) of the top corners are cut, starting with points totaling one-third the depth of the corner, then cut one-point and two-bars the remainder of the length. The sewing edge of the corner, attached to the body, is cut one-mesh and four-bars. This shifts the wing at a greater angle than the jib trawl for increased horizontal spread. The sewing edge of the corner, attached to the wing, is cut on all points to reduce webbing distortion. The bottom corner pieces are cut on all points for one-third the depth of the corner, then tapered two-bars and two-points for the remainder of the hanging edge, making the bottom corner longer than the top corner. Hanging coefficients for the super X-3 are 70.83% along the body panel and points of the corner hanging edge.

Shrimp trawling gear has undergone some significant changes in the past few years, including changes in rigging. The twin trawl now uses four small trawls (two from each outrigger) instead of one larger trawl on each outrigger. This rigging configuration is more efficient and produces larger catches than the double-rigged configuration, but requires extra rigging of an additional bridle and a dummy door, sled, or bullet between the paired trawls (Harrington et al. 1972; Captiva 1980). The additional rigging creates tangling and handling problems. To overcome the handling problems characteristic of the twin trawl system, the University of Georgia Marine Extension Center and several trawl manufacturers have been experimenting with a new trawl design called the bib or tongue trawl. The innovative feature is a "tongue" of webbing extending forward from the net's top panel and connecting to a third central bridle. The basic principle of the design is to reduce the total net and cod end load on the doors by transferring a portion of it to the tongue and central bridle, allowing the trawl to achieve and maintain a maximum effective horizontal spread.

Any conventional shrimp trawl can be converted to a tongue trawl by adding a tongue. Several tongue trawl designs are currently being marketed, including the most popular Cobra and Mongoose designs.

Cobra Trawl

The Cobra trawl is a semiballoon trawl with a tongue added to the top body panel (Fig. 7). The triangular tongue is sewn to the top body panel, overlapping the small jib corners.

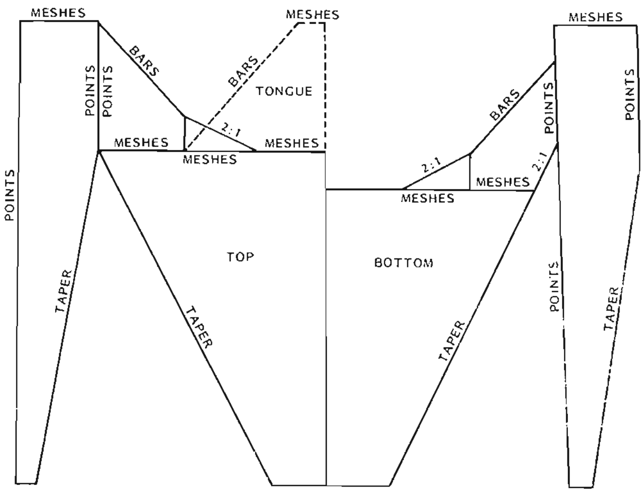

Figure 7.—Cobra trawl generalized schematic.

Mongoose Trawl

The Mongoose trawl (Fig. 8) is unique in that the tongue is built into the top body panel. The corners, top body panel, and tongue are all cut from one section of webbing. The wing sewing edge of the top panel is cut on points for the first 10-13 meshes; the remainder of the length is cut on a body taper. All bars are used on the hanging edge of the tongue and what is normally the corner section; a two-mesh and two-bar taper is cut on the hanging edge in the area where the small jib corner is normally located. The hanging edge of the body is cut on all meshes to the section where the tongue begins. Another two-mesh and two-bar taper is cut at the base of the tongue. The remaining length of the tongue is cut on all bars. The bottom body panel and corners are also cut from a single section of webbing. The bottom corners are longer and narrower than the top corners, helping produce setback in the Mongoose. The bottom corner hanging edge is all bars up to the jib type corner which is cut on two-meshes and two-bars, similar to the top body. The body hanging edge is all meshes. The hanging coefficient for the Mongoose is 66.6% on the body and 100% on the corners and tongue.

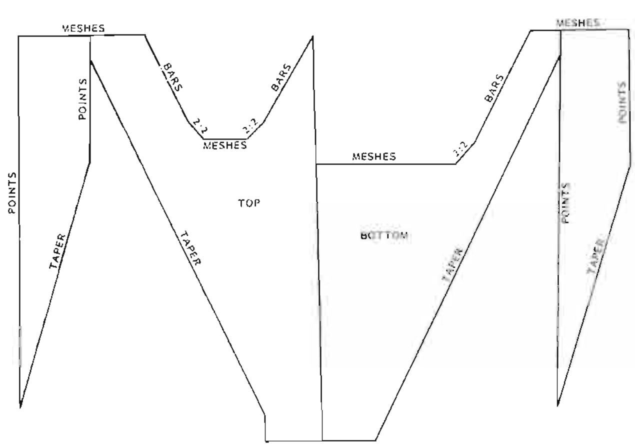

Figure 8.—Mongoose trawl generalized schematic.

METHODS

The trawl types and rigging configurations used by 47 commercial vessels were evaluated by scuba diving techniques. Measurements of shrimp trawl gape dimensions were made from a 68-ft Desco-built fiberglass trawler with a 365-hp Cummins diesel engine employing a 6:1 reduction gear. The resulting trawl-dimension measurements represent a sampling of the shrimp trawling gear and rigging configurations used in the southeastern U.S. shrimp fishery.

Measurements were made off Panama City, Fla., in 4-6 fathoms of water at a towing speed between 2 and 3 kn. Towing speed was measured with a General Oceanics Model 2035 flowmeter. Towing bridle length varied between 40 and 50 fathoms to correspond to the rigging used by each of the individual cooperative vessels. A warp ratio of 10:1 (towing warp to water depth) was used. The trawl measurements taken on each net included: Horizontal spread, vertical opening, and footrope height. These measurements were taken by research divers using special trawl diving techniques (Wickham and Watson 1976) and measuring gear specifically designed for use on trawls under tow.

Horizontal spread, as defined for the purpose of this paper, is the spread of the trawl measured from the first hanging on each trawl wing (webbing to webbing) and does not include the leglines or doors. The horizontal spread measurement used is the actual fishing area covered by the webbing and cannot be compared with any spread measurement derived from bridle angles which includes the spread distance from door to door. Horizontal spread measurements were made by two divers using a ⅛-in diameter stainless steel cable marked in 1-ft increments. The cable was stretched across the mouth of the trawl with one end attached to the first hanging on one wing and the other cable end pulled through a metal ring sewn to the first hanging on the opposite wing. The cable was pulled taut across the mouth of the net by one diver while the other diver recorded the spread reading. Vertical opening (vertical distance between the trawl headrope and footrope) was measured at the center of the trawl using a fiberglass measuring rod marked in 6-in increments. Two measurements were made on each trawl (cod ends empty) to determine vertical opening height. The first measurement was made at the center of the trawl headrope and measured the height of the headrope from the sea floor. The second measurement was made at the center of the footrope and measured the height of the footrope from the sea floor. The vertical opening was then calculated by subtracting the two measurements. To insure that the diver's body weight and drag did not affect the readings, the divers were suspended above the trawl on a separate towing line.

Rigging configuration of the various trawls were recorded: Headrope length (webbing to webbing), total headrope length (including legline lengths), door size, number and size of floats, number and type of footrope weight (loop chain), size and length of tickler chain, door chain setting, and trawl construction (webbing and twine size, hanging ratios, and tapers). Measurements were also made on warp tension using Dillon dynamometers and on fuel consumption rates using a prototype fuel meter from Electronic Concepts, Inc., for a limited number of tows with the Mongoose trawl.

RESULTS

Spread and height measurements for 76 fishing configurations of eight types of otter trawls (by trawl type and in order of increasing headrope length) are presented in Appendix Tables 1-8.

Comparison of Trawl Gape Dimensions

Relative fishing dimensions of the eight common shrimp trawl types used by the shrimp industry are presented in Table 1. Each trawl was 60 ft in headrope length, constructed to standard specifications by a commercial trawl manufacturer. Trawls were rigged with standard loop chain and no flotation, spread by 8-ft × 40-in chain doors of standard construction. Measurements were taken by scuba divers in 5 fathoms of water using 50-fathom bridles set to the water at a towing speed between 2.5 and 3.0 kn. The measured horizontal spread varied from 40 ft (67%) for flat and semiballoon trawls to 48-50 ft (80-85%) for the tongue trawl designs. The super X-3 trawl had the best horizontal spread (73%) of the conventional (nontongue) trawls, and the balloon trawl had a slightly better spread than the flat, semiballoon, and jib trawls. The vertical height of the trawls varied from 2.0 ft for the super X-3 tongue to 4.0 ft for the flat, semiballoon, and Mongoose trawls. The Mongoose tongue trawl had the best total gape opening with an 80% horizontal spread and a corresponding vertical opening of 4.0 ft. The relative gape dimensions between 70 ft headrope length flat, balloon, and semiballoon trawls on 9-ft × 40-in doors are shown in Table 2. The best horizontal spread was achieved by the balloon trawl (70%) with a vertical height of 2.5 ft. The semiballoon had a better horizontal spread than the flat trawl with the same vertical height.

The relative gape dimensions of flat and semiballoon trawls with and without added flotation on the headrope (Table 3) show that the addition of flotation significantly changed the fishing configuration of these trawls. The addition of 10 6-in × 8-in spongex floats to a 60-ft flat trawl on 8-ft × 40-in doors increased the vertical opening from 4.0 to 11.5 ft while decreasing the horizontal spread by 12%. The addition of 20 6-in × 8-in spongex floats to a 70-ft flat trawl on 9-ft × 40-in doors increased the vertical opening from 4.0 to 11.0 ft and decreased the horizontal spread 10%. Fourteen 6-in × 8-in spongex floats on a 50-ft semiballoon using 7-ft × 36-in doors increased the vertical opening from 3.0 to 8.0 ft and reduced the horizontal spread by 8%. The vertical height of a 68-ft semiballoon trawl on 9-ft × 40-in doors was increased from 4.0 to 7.0 ft with the addition of 20 6-in × 8-in spongex floats, while the horizontal spread decreased 5%. These data indicate that with the same amount of flotation, the flat trawl is capable of attaining a greater vertical opening than the semiballoon trawl but has a corresponding greater decrease in horizontal spread.

The effect of increasing door size on horizontal spread and vertical opening for a 60-ft super X-3 trawl is shown in Table 4. The horizontal spread for the 60-ft trawl on 7-ft × 36-in doors was 62% with a vertical opening of 4.0 ft. When the door size was increased to 8-ft × 40-in, the horizontal spread increased to 72% and the vertical opening decreased to 3.5 ft. With 10-ft × 40-in doors the horizontal spread increased to 77% and the vertical opening decreased to 3.0 ft.

The effect on gape dimension of adding a tongue modification to 60-ft flat, semiballoon, and super X-3 trawls on 8-ft × 40-in doors is presented in Table 5. The addition of tongues to these trawls resulted in a spread increase of 5% for the flat

Table 1.—Comparison of gape dimensions for eight 60-ft trawls with 8-ft × 40-in doors.

Trawl type	Spread (ft)	Vertical opening (ft)	Spread ratio (%)
Flat	40	4.0	67
Semiballoon	40	4.0	67
Western jib	41	3.5	68
Balloon	42	3.5	70
Super X-3	44	3.5	73
Super X-3 tongue	51	2.0	85
Cobra/Hood	49	2.5	82
Mongoose	48	4.0	80

Table 2.—Relative gape dimensions between 70-ft flat, balloon, and semiballoon trawls on 9-ft × 40-in doors.

Trawl type	Headrope length (ft)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
Flat	70	4.0	44	63
Semiballoon	68	4.0	46	68
Balloon	70	2.5	49	70

Table 3.—Relative gape dimensions of flat and semiballoon trawls with and without floats.

Trawl type	Headrope length (ft)	Door size (ft × in)	No. of 6″ × 8″ spongex floats	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
Flat	60	8 × 40	0	4.0	40	67
Flat	60	8 × 40	10	11.5	33	55
Flat	70	9 × 40	0	4.0	44	63
Flat	70	9 × 40	20	11.0	37	53
Semiballoon	50	7 × 36	0	3.0	35	70
Semiballoon	50	7 × 36	14	8.0	31	62
Semiballoon	68	9 × 40	0	4.0	46	68
Semiballoon	68	9 × 40	20	7.0	43	63

Table 4.—Relative gape dimensions for 60-ft super X-3 trawls with increasing door size.

Door size (ft × in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
7 × 36	4.0	37	62
8 × 40	3.5	43	72
10 × 40	3.0	46	77

Table 5.—Comparison of gape dimensions between 60-ft flat, semiballoon, and super X-3 trawls with and without tongue on 8-ft × 40-in doors.

Trawl type	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)	Increase in spread ratio (%)
Flat	4.0	40	67	5
Flat w/tongue	3.0	43	72	
Semiballoon	4.0	40	67	15
Semiballoon w/tongue	2.5	49	82	
Super X-3	3.5	43	72	13
Super X-3 w/tongue	2.0	51	85	

Table 6.—Spread ratio comparison for super X-3 trawls with and without tongues.

Trawl type	Headrope length (ft)	Door size (ft × in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)	Spread increase (%)
Super X-3	50	7 × 36	3.0	36	72	8
Super X-3 w/tongue	50	7 × 36	3.0	40	80	
Super X-3	55	9 × 40	3.0	44	80	9
Super X-3 w/tongue	55	9 × 40	3.0	49	89	
Super X-3	60	10 × 40	3.0	46	77	6
Super X-3 w/tongue	60	10 × 40	3.5	50	83	
Super X-3	65	8 × 40	3.0	45	69	8
Super X-3 w/tongue	65	8 × 40	3.0	50	77	
Super X-3	65	10 × 40	3.0	49	75	7
Super X-3 w/tongue	65	10 × 40	3.5	53	82	
Super X-3	70	9 × 40	4.0	45	64	10
Super X-3 w/tongue	70	9 × 40	4.0	52	74	

trawl, 13% for the super X-3, and 15% for the semiballoon. Vertical opening decreased from 4.0 to 3.0 ft for the flat, 4.0 to 2.5 ft for the semiballoon, and 3.5 to 2.0 ft for the super X-3. Table 6 shows the spread ratio comparison for five headrope-length super X-3 trawls on four trawl door sizes with and without the tongue modifications. Spread ratios increased from 6 to 10% on the different trawl-to-door-size combinations when the tongue rigging was added. The maximum spread achieved was 89% for a 55-ft super X-3 on 9-ft × 40-in doors.

The use of tongue trawls requires the addition of a third bridle which is attached to the tongue. The bridles most commonly used by the shrimp industry are 40 to 50 fathoms long with the three legs of the bridle equal in length. Most tongue trawls are constructed with the tongue about the same depth as the corners, requiring an extension on the middle bridle leg to compensate for the length of the leglines and doors. Tension on the middle bridle cable is an important factor in adjusting the tongue trawl to obtain an optimum fishing configuration. Data on the relative gape dimensions for trawls at different middle bridle extension lengths for 40- and 50-fathom bridles are shown in Tables 7 and 8. These data indicate the extension setting for optimum spread for the two bridle lengths when towed in 5-6 fathoms of water. These settings may not be optimum for deeper water depths where longer extensions are needed, due to the change in towing wire angle. The optimum extension length for the 40-fathom bridles (Table 7) was 10 ft with the optimum range between 9 and 12 ft and 8 ft for the 50-fathom bridles (Table 8) with an optimum range between 6 and 10 ft.

Table 9 shows the relative gape opening measurements between 70-ft semiballoon, flat, and Mongoose trawls on 9-ft × 40-in doors with maximum effective flotation. The maximum vertical opening is achieved by the flat and the Mongoose tongue trawls with a height of 11 and 10 ft, respectively. The semiballoon trawl had a vertical opening of only 7 ft. The Mongoose trawl had the best total gape dimension with a 16% increase in horizontal spread over the flat trawl. The measurements of gape dimensions for a 60-ft Mongoose trawl on 9-ft × 40-in doors with increasing flotation are given in Table 10. The vertical opening for the Mongoose increased from 5.5 ft with no floats to 12.0 ft with 24 6-in × 8-in spongex floats. Horizontal spread decreased from 70 to 65%.

The relationship between trawl door size and headrope length and the relative spreading efficiency is presented in Figure 9 for conventional trawl designs and in Figure 10 for tongue trawl designs. The ratio of door size to headrope size is expressed as the number of square inches of door area for one door per headrope foot. For example, a 9-ft × 40-in door has a total area of 4,320 in². When used on a 60-ft headrope trawl, the door/headrope ratio would then be 4,320/60 = 72 in² per

Table 7.—Effect of middle bridle length setting on spread of tongue trawls employing 40-fathom bridles.

Headrope length (ft)	Door size (ft × in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)	Middle bridle extension (ft)
60	9 × 40	6.0	43	72	9
60	9 × 40	6.0	45	75	10
60	9 × 40	6.0	44	73	11
60	9 × 40	6.0	44	73	12

Table 8.—Effect of middle bridle length setting on spread of tongue trawls employing 50-fathom bridles.

Headrope length (ft)	Door size (ft × in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)	Middle bridle extension (ft)
60	8 × 40	3.5	42	70	6
60	8 × 40	3.0	43	72	8
60	8 × 40	3.5	42	70	10
65	8 × 40	4.0	50	77	8
65	8 × 40	4.0	47	72	10
[1]50	7 × 36	8.0	35	70	8
[1]50	7 × 36	8.0	34	68	9
[1]50	7 × 36	8.0	34	68	10
[1]50	7 × 36	8.0	34	68	12
[1]50	7 × 36	8.0	33	66	14

[1] 24 (6″ × 8″) spongex floats on headrope

Table 9.—Relative gape opening measurements between 70-ft flat, semiballoon, and Mongoose trawls on 9-ft × 40-in doors with maximum effective flotation.

Trawl type	No. of 6″ × 8″ spongex floats	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
Flat	20	11	37	53
Semiballoon	20	7	43	63
Mongoose	24	10	48	69

Table 10.—Gape dimensions for 60-ft Mongoose trawl on 9-ft × 40-in doors with varied number of floats.

No. of 6" × 8" spongex floats	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
0	5.5	42	70
6	6.5	42	70
12	7.5	41	68
18	10.0	40	67
24	12.0	39	65

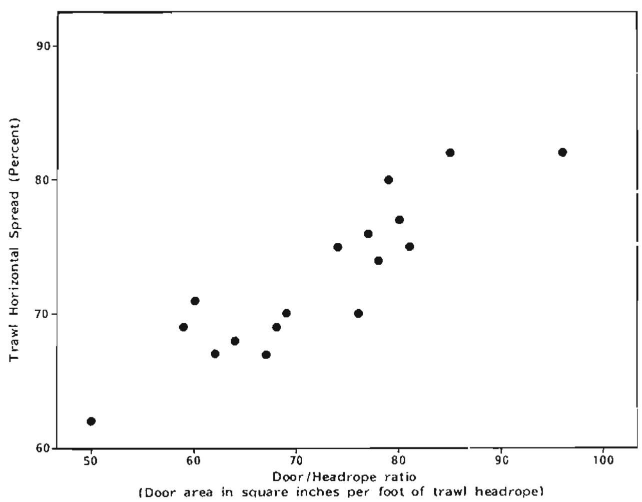

Figure 9.—Relationship between trawl door dimension, headrope length, and horizontal spread for conventional trawl designs.

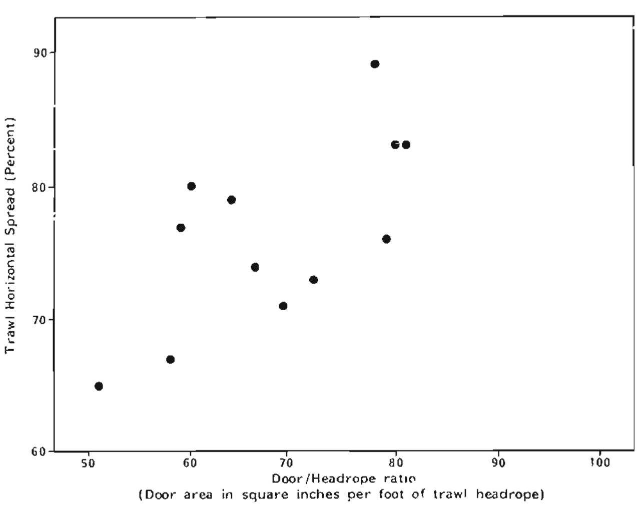

Figure 10.—Relationship between trawl door dimension, headrope length, and horizontal spread for tongue trawl designs.

headrope foot. The maximum spread achieved for conventional trawls was 82% with a door/headrope ratio of 85 in^2. A spread ratio between 70 and 75% required a door/headrope ratio of 70-80 in^2. An increase in the door/headrope ratio above 85 in^2 did not increase the spread ratio. The maximum spread for tongue trawls was 89% with a door/headrope ratio of 78 in^2. A spread ratio of 75-80% required a door/headrope ratio of 60-75 in^2. Door/headrope ratios exceeding 80 in^2 were not tested for the tongue trawls.

Operating Characteristics

A limited amount of data was collected on the operating characteristics of trawls while fishing to investigate possible methods for increasing efficiency and reducing energy costs. Table 11 and Figure 11 present data on the relationship between towing tension, engine RPM, fuel consumption, trawling speed, and horizontal spread and tow duration as a measure of trawl loading on a 65-ft Mongoose trawl using 10-ft × 44-in doors. Towing tension increased as the trawl load increased but appeared to reach an equilibrium between 90 and 180 min. (Fig. 11). Table 11 shows that with initial engine throttle setting unchanged, the engine RPM decreased from 1,650 to 1,636 after 150 min while the fuel consumption increased from 13.7 gal/h to 14.2 gal/h, and speed decreased from 3.3 to 2.5 mph. The horizontal net spread decreased from 54 to 44 ft with a total bag load of 1,340 lb. These measurements, taken during optimum weather conditions with calm seas, wind < 5 mph, and no current, could not be duplicated when weather conditions were less than optimum, due to the variability in the tension measurements. Figure 12 shows the relative fuel consumption rates over a range of RPM settings when the vessel was running and when the vessel was towing two 65-ft Mongoose trawls on 9-ft × 44-in doors. The data indicate a significant increase in fuel consumption due to the towing resistance of the trawls. The data collected on fuel consumption and trawl operating characteristics are preliminary. More data

Table 11.—Operating characteristics of a 65-ft Mongoose shrimp trawl during a 150-min tow. Trawl towed on 10-ft × 44-in doors with 50-fathom bridles in 5-6 fathoms of water with a warp ratio of 5:1.

Time (min)	Engine RPM	Fuel consumption (gal/h)	Speed (mph)	Horizontal spread (ft)
0	1,650	13.7	3.3	54
30	1,642	13.8	2.9	—
60	1,647	13.9	3.1	—
90	1,643	14.0	2.9	—
120	1,642	14.0	2.9	—
[1]150	1,636	14.2	2.5	44

[1] Total catch weight after 150 min was 1,340 lb of finfish and invertebrates.

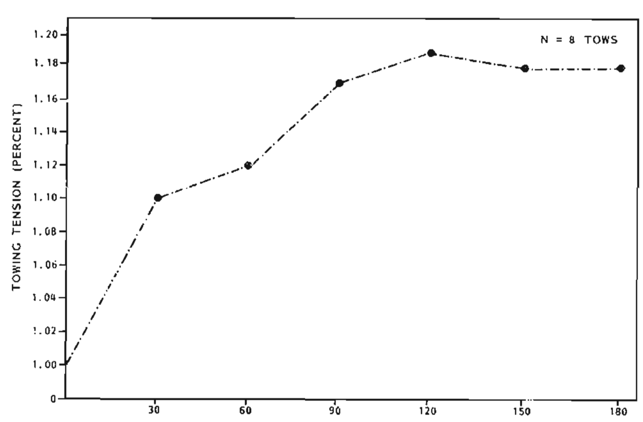

Figure 11.—Measurements of towing tension at 30-min. intervals for a 65-ft Mongoose on 10-ft × 44-in doors. Mean catch rates = 634 lb.

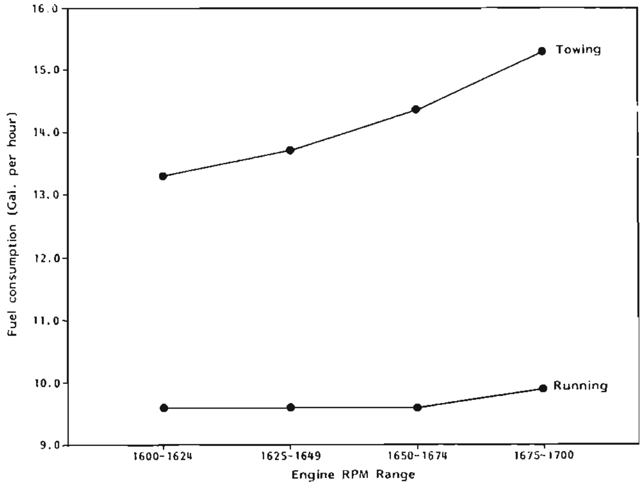

Figure 12.—Fuel consumption rates for various RPM operating ranges while running and towing.

will be collected to determine possible methods of reducing fuel consumption during the fishing operation by modifying fishing tactics and developing more fuel efficient trawling gear.

DISCUSSION

There are currently eight basic designs of the otter trawl used in the southeastern United States shrimp fishery. Some modifications to these basic designs have not been presented in this paper; innumerable rigging configurations are employed by individual fishermen. The data presented represent trawl designs and rigging configurations employed by vessels that cooperated in the turtle excluder trawl research and are not a complete synopsis of the gear used by the shrimp industry. They do, however, indicate some relative efficiencies among basic trawl designs and suggest some optimum rigging configurations and gear for different fishing conditions.

Rigging configuration of trawls and trawl types are changed by individual fishermen to optimize their gear for the prevailing conditions. The behavior of shrimp, for example, determines the optimum fishing configuration for harvesting different species. Shrimp occur in different positions in the water column, particularly when migrating from the estuary. White shrimp are known to occur 10-12 ft above the bottom, whereas pink and brown shrimp generally remain in close proximity to the bottom. For trawl efficiency, fishermen add flotation to their trawls, increasing the vertical opening when shrimp occur off the bottom, and optimize their rigging for horizontal spread when shrimp are near the bottom. Fishing configurations are also changed to reduce unwanted bycatch such as jellyfish, sponges, bottom trash, and finfish, and to optimize gear for different substrate conditions (mud, sand, shell, rock, etc.). As a result, there is no ideal traw design or rigging configuration to suit every situation. Trawling gear must be constantly checked and the rigging modified in order to maintain optimum shrimp production.

Measurements of the gape dimension for the different trawl types and rigging configurations suggest that some designs are better suited to some fishing conditions than others. Comparisons of the conventional designs of the same size indicate that for conditions where optimum spread is required, the super X-3, jib, and balloon trawls perform better than the flat and semiballoon and the semiballoon better than the flat trawls. In conditions where vertical height is required, the flat trawl outperforms the other designs with the semiballoon performing better than the balloon, jib, and super X-3. The addition of the tongue modification improves the spreading characteristic of all the trawl designs tested, with the best performance demonstrated by the super X-3 tongue trawl followed by the semiballoon tongue or Cobra trawl. The best overall gape dimensions for maximum vertical height and spread were demonstrated by the Mongoose tongue trawl. The tongue trawls outperformed the conventional trawls in every respect provided the rigging adjustments were correct, particularly the middle bridle extension settings. There has been some indication from shrimp fishermen that tongue trawls do not operate efficiently in deeper water. Our research indicates that the tongue trawls are efficient in deep water but that some rigging adjustments are necessary because of change in warp angle. The increased warp angle in deeper water tends to cause the trawl doors to "nose" because of the tension and angle of the headrope on the back of the door. This causes the trawl footrope to be pulled off the bottom in the wings, reducing efficiency. This problem was corrected by using longer warps, or by adding more length on the middle bridle extension and extra weight to the heel of the doors.

Twin trawl rigging is being employed by a growing number of trawlers, particularly in the Gulf of Mexico. Reports from shrimp fishermen indicate that catch rates for brown and pink shrimp have increased significantly with the use of twin trawls. Two twin trawls were measured during this study (Appendix Tables 4, 5). Measurements of horizontal spread for the twin trawls did not indicate any significant increase over double-rigged trawls. The advantage of the twin-rigged trawls is that a vessel can tow more total trawl headrope length using four small trawls rather than two large trawls with the same horsepower. Data on energy efficiency of shrimp trawl designs indicate that twin trawls sweep a larger total area per gallon of fuel than do double rigged trawls (Watson[2]).

Door size used on various trawls varies from vessel to vessel and usually depends on vessel size and horsepower. Our data indicate that the spread of the trawl increases with door size. The increase in spread gained by using larger doors may, however, be offset by the increased cost in fuel consumption. The data indicate that for conventional trawls a range of 70-80 in^2 (per door) of door area is required for each foot of headrope length to obtain a horizontal spread of 70-75%, while only 60-75 in^2 of door area per foot of headrope length were required on tongue trawls to obtain spreads of 75-80%. These data suggest that smaller doors could be used on tongue trawls to achieve the same spread ratio as conventional trawls, resulting in fuel savings.

One of the most critical problems facing the fishing industry in the United States is the increasing cost of energy. To keep the industry viable and promote a healthy economy more research is required to determine fuel consumption rates, fishing tactics, and gear efficiency to optimize production while reducing costs.

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Appendix Table 1.—Spread and height measurements for flat trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
40	46	8 × 40	5 (6 × 8)	3.0	30	75
42	54	6 × 36	1 (6 × 8)	3.0	29	69
42	58	6 × 36	1 (6 × 8)	3.0	30	71
42	54	6 × 40	1 (6 × 8)	3.0	29	69
50	62	8 × 40	1 (6 × 8)	3.5	38	76
60	72	8 × 40	0	4.0	40	67
60	72	8 × 40	1 (6 × 8)	4.0	41	68
60	72	8 × 40	10 (6 × 8)	11.5	33	55
65	77	9 × 40	7 (6 × 8)	4.0	43	66
68	78	10 × 44	0	3.5	50	74
70	82	9 × 40	1 (6 × 8)	4.0	44	63
70	82	9 × 40	20 (6 × 8)	11.0	37	53
75	87	10 × 40	0	4.0	50	67
75	87	10 × 40	15 (6 × 8)	9.0	38	51

Appendix Table 2.—Spread and height measurements for western jib trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
45	53	7 × 36	0	3.0	30	67
45	57	8 × 40	5 (6 × 8)	3.0	37	82

Appendix Table 3.—Spread and height measurements for two-seam balloon trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
65	77	10 × 44	0	4.0	49	75
70	87	9 × 40	1 (6 × 8)	2.5	49	70
70	82	10 × 40	7 (6 × 8)	3.5	49	70

Appendix Table 4.—Spread and height measurements for semiballoon trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
40	52	8 × 40	5 (6 × 8)	4.0	35	88
[1]45	53	9 × 40	0	3.0	36	80
[1,2]45	53	9 × 40	0	3.0	33	73
45	57	8 × 40	5 (6 × 8)	3.5	37	82
50	62	7 × 36	1 (6 × 8)	3.0	35	70
50	62	7 × 36	14 (6 × 8)	8.0	31	62
60	72	8 × 40	0	4.0	40	67
68	80	9 × 40	1 (6 × 8)	4.0	46	68
68	80	9 × 40	20 (6 × 8)	7.0	43	63

[1] Twin trawl.
[2] Rigged with ¼ in tickler chain set 36 in shorter than footrope length.

Appendix Table 5.—Spread and height measurements for super X-3 trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
[1]40	46	7 × 36	1 (6 × 8)	3.5	28	70
50	62	7 × 36	0	3.0	36	72
55	67	9 × 40	0	3.0	44	80
60	72	7 × 36	0	4.0	37	62
60	72	8 × 40	0	3.5	43	72
60	72	10 × 40	0	3.0	46	77
65	77	8 × 40	0	3.0	45	69
65	77	8 × 40	8 (6 × 8)	8.0	40	62
65	77	8 × 40	13(6 × 8)	10.0	41	63
65	77	10 × 40	0	3.0	49	75
70	82	9 × 40	5 (4 × 6)	4.0	45	64

[1] Twin trawl.

Appendix Table 6.—Spread and height measurements for super X-3 with tongue trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)	Bridle length (ft)	Middle bridle extension
50	62	7 × 36	5 (4 × 6)	3.0	40	80	300	+8
55	67	9 × 40	7 (4 × 6)	3.0	49	89	300	+8
60	72	8 × 40	0	2.0	51	85	300	+8
60	72	8 × 40	12 (6 × 8)	3.5	46	77	300	+8
60	72	8 × 40	8 (6 × 8)	4.0	47	78	300	+8
60	72	8 × 40	10 (6 × 8)	5.0	46	77	300	+8
60	72	10 × 40	5 (4 × 6)	3.5	50	83	300	+8
65	72	8 × 40	0	3.0	50	77	300	+8
65	77	10 × 40	5 (4 × 6)	3.5	53	82	300	+8
70	82	9 × 40	9 (4 × 6)	4.0	52	74	300	+8
76	88	10 × 44	0	4.0	54	71	300	+8

Appendix Table 7.—Spread and height measurements for Mongoose trawls employed in the southeastern U.S. shrimp fishery.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)	Bridle length (ft)	Middle bridal extension
40	52	8 × 40	10 (6 × 8)	10.0	29	72	240	
50	62	7 × 36	24 (6 × 8)	8.0	35	70	300	
55	67	8 × 40	24 (6 × 8)	7.0	39	71	300	
55	67	9 × 40	0	4.0	42	76	240	
55	67	9 × 40	24 (6 × 8)	7.0	40	73	240	
60	72	9 × 40	0	5.5	42	70	240	
60	72	9 × 40	6 (6 × 8)	6.5	43	72	240	
60	72	9 × 40	12 (6 × 8)	7.5	41	68	240	
60	72	9 × 40	18 (6 × 8)	10.0	40	67	240	
60	72	9 × 40	24 (6 × 8)	12.0	39	65	240	
60	72	9 × 40	0	6.0	44	73	240	
60	72	9 × 40	0	6.0	43	72	240	
60	72	9 × 40	0	6.0	45	75	240	
60	72	9 × 40	0	6.0	44	73	240	
60	72	9 × 40	0	5.5	44	73	240	
60	72	9 × 40	0	5.5	45	75	240	
60	72	9 × 40	24 (6 × 8)	11.0	42	70	240	
65	77	9 × 40	0	5.5	48	74	240	
65	77	10 × 40	0	3.5	54	83	300	
65	77	10 × 44	12 (6 × 8)	5.0	52	80	300	+ 8
70	82	9 × 40	24 (6 × 8)	10.0	48	69	300	+ 8
72	84	9 × 40	24 (6 × 8)	10.0	49	68	300	+ 8
75	87	8 × 40	0	6.0	49	65	240	+10
75	87	9 × 40	0	6.0	50	67	240	+10
75	87	10 × 40	0	6.0	52	69	240	+10

Appendix Table 8.—Spread and height measurements for Cobra trawl.

Headrope length (ft)	Total headrope and legline length (ft)	Door size (ft × in)	No./size floats (in)	Vertical opening (ft)	Horizontal spread (ft)	Spread ratio (%)
60	72	8 × 40	0	2.5	49	82