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Mesh Size and New England Groundfish

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79-02

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Laboratory Reference No. 79-02
January 1979

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Abstract

Cod-end mesh size experiments were conducted aboard eight New England otter trawlers during the period December 1977 to October 1978. This paper summarizes the results of these experiments and reviews the impacts and implications of mesh size management.

Introduction

For hundreds of years men have been harvesting groundfish off the shores of New England. Until 1905 this fishery consisted almost entirely of sailing vessels using hand lines and trawl lines. In 1905 the Bay State Fishing Co. of Boston built the first American steam otter trawler at Quincy, Massachusetts, the steamer Spray. By 1912 there were 11 steam-driven otter trawlers from New England fishing groundfish.

With the rapid rise of this new fishing method, the line fishermen grew apprehensive about the conservation of their fishery. This resulted in a government act approved August 24, 1912, making appropriations as follows:

> To enable the Commissioner of Fisheries to investigate the method of fishing known as beam or otter trawling and to report to Congress whether or not this method of fishing is destructive to the fish species or is otherwise harmful or undesirable, $5,000, or so much thereof as may be necessary.

Alexander, Moore, and Kendall (1915) began the work that year. Some of their tasks were to determine:

(a) The general effects of trawl nets and hook gear on the fish populations.

(b) The nature and extent of the destruction of juvenile fish.

(c) The waste of "edible fishes that have no present market value" ~~(underutilized fish).~~

(d) The extent that trawl nets catch fish not taken by other gear.

(e) Any evidence of depletion of fish stocks by trawl nets.

(f) If there were any gear conflicts.

(g) The necessity of international agreements to regulate the fisheries.

They state in their report that the average mesh sizes (measured between knots) used by otter trawlers were 6 inches in the forward parts of the net, 3 inches in the bellies, and 2.5 inches in the cod end. They found that 30-40% of the cod and haddock caught by these nets were too small to market. They concluded that not only does the otter trawl destroy more undersized fish than line trawls, but that it is more destructive to the fish stocks because of the smaller average size of the landings.

When it came time to make their recommendations they noted that certain European authorities had proposed increasing the size of the meshes of the net to let the small fish escape. The American authors felt this would not be a feasible approach because they believed that (a) the meshes tend to close as the trawl catches fish, (b) the fish in the cod-end block escape, (c) the fish would not attempt to escape until haulback, and (d) more fish would be gilled in the larger meshes.

They also recommended against banning otter trawls or limiting entry. They liked the idea of area restrictions for otter trawlers and made this their sole proposal. However, industry did not support this recommendation and thus no action was taken (Herrington 1935).

While these events were occurring in New England, considerable research was taking place in Europe concerning "savings gear": Herrington (1935), reference work done by Fulton (1893), Holt (1895), Gilson (1904), Heincke (1905), Redeke (1906), Todd (1911), Johnstone (1911), Ridderstad (1915), Pettersson (1925), Fulton (1921), Borley and Russel (1922), Wallace (1923), Russel and Edser (1926), Bowman (1928), Davis (1929), Borowik (1930), Buchanan-Wollaston (1929), and Davis (1934). It was fairly well established by the 1930's that a definite relationship existed between cod-end mesh size and the escapement of small fish from the trawl.

During the 1920's a new market for fresh and frozen haddock fillets was developed. The large demand for this product resulted in the New England otter trawler fleet growing to 323 vessels by 1930. The catch of haddock grew from 93,500,000 pounds in 1924 to 256,000,000 pounds by 1929 (Herrington 1936); then came a rapid decline. Industry grew concerned and funds were allotted to the Bureau of Fisheries to study the haddock fishery.

The study soon identified two major causes of the decline. The first was the failure of annual spawning for several years; the second, a high rate of fishing mortality, this latter factor possibly influencing the spawning failures. A good percentage, as high as 75%, of the haddock being caught were undersized (22-42 cm) and discarded at sea. Herrington (1932) estimates that in 1930 37,000,000 haddock were landed and as many as 90,000,000 were discarded.

Herrington (1935) conducted mesh experiments aboard the research vessel Albatross II and the commercial draggers Exeter and Kingfisher using "trouser trawls" and large mesh cod ends (about a 5-inch mesh). He recommended, from the results of this work, that industry adopt at least a 4 3/4-inch mesh size and that even a 5 1/4-inch mesh should be considered. Many leading captains were already fishing large-mesh trawls.

In 1934 the haddock landings had dropped to 50,000,000 pounds and then steadily increased to 122,000,000 pounds by 1941. From 1941 to 1951 the average annual landings from Georges Bank was 96,000,000 pounds. There were no definite trends in abundance evident so the fishery was assumed to be in some state of equilibrium (Graham 1952a). During this period the commonly used cod ends averaged 2 7/8 inches stretched mesh (Graham 1952b).

Graham (1952a) estimated that the annual discard rate of small haddock during this equilibrium period was over 5,000,000 pounds. It was felt that if this destruction could be decreased the fishery could be stabilized at a

higher level of production, as long as there weren't any major changes in the socioeconomic relationships.

At the first annual meeting of the International Commission for the Northwest Atlantic Fisheries (ICNAF) in 1951 the subject of protecting the small haddock received much attention, and by June 1953 a 4 1/2-inch mesh size (stretched mesh) went into effect on Georges Bank and in the Gulf of Maine (Graham and Premetz 1955). The idea was to advance the age of first capture (actually the 50% retention length of first capture) to 3 years in two steps so as to avoid major short-term reduction in catch. The 4 1/2-inch mesh size was the first step and was calculated to advance the age of first capture to 2 1/2 years. This was calculated to increase the annual landings to a level 30% higher than the existing equilibrium if fishing effort remained constant (Graham 1954).

After the first step was taken the plan was to monitor the effects of the regulation. This was performed by issuing special licenses to several trawlers (eight in 1953) to fish small mesh nets while the remainder of the fleet fished the new larger regulation mesh.

There was objection to the new mesh size by many in the industry. Graham (1954) quotes fishermen as saying "We can't possibly make a living fishing with a large mesh like that." "This won't hold any fish at all. They'll all get through." However, by the end of the first year of regulation the results were showing up. The large-mesh nets were more efficient in capturing larger fish to the point that they landed more fish (by weight) than the small mesh in three of the four quarters of the first year of regulation (Graham and Premetz 1955).

During the 1950's extensive gear studies were carried out by many nations in ICNAF areas. The majority of the work was on otter trawl (cod end)

selectivity for haddock; lesser amounts on cod, redfish, American plaice, and silver hake. Clark, McCracken, and Templeman (1958) summarized the gear-selection information for the ICNAF area up until 1958. These experiments in the ICNAF area, along with numerous experiments in Europe, tremendously improved the state of knowledge on selectivity.

Two major publications summarize this state of knowledge. The first contains 24 papers given at the Joint ICNAF/ICES/FAO special scientific meeting in Lisbon in 1957 (ICNAF 1963). The second is the report of the ICES/ICNAF working groups on selectivity analysis edited by M. J. Holden (1971). This report contains an extensive bibliography and tabulation of selectivity experiments.

In 1961 a working group of ICNAF scientists met to discuss the possible effects of mesh size increases (4 to 6 inches) on cod, haddock, redfish, and other species (ICNAF 1962). Their conclusions did not take into account the large increase in fishing effort that soon followed, and thus underestimated the benefits of increasing mesh size (Templeman and Gulland 1965).

(*1951-1975 Catch/Fishery Data*)

In March of 1977 the Fisheries Management and Conservation Act became law forming regional councils to manage area fisheries. Also in 1977 a large year class of 2-year-old haddock entered the Georges Bank fishery and there was a major discard of undersized fish. This cooperative study, under the auspices of the New England Regional Fishery Management Council, began in late 1977 to study the possible effects of increasing the mesh size.

Selectivity

Selectivity is the measure of the process of selection; the process in which a subgroup of a population is distinguished from the whole. The characteristics that create the selection process can be almost anything intrinsic to a particular fish: size, shape, sex, and behavior. The fishing gear and methods used and the area fished will determine what species and size fish will be selected from the overall population.

In this paper we are primarily concerned with the size selectivity of the cod ends of otter trawls used in the New England groundfishery. The forward parts of the trawl do effect the size selection of the trawl, but the study of these effects is beyond the scope of this paper.

As mentioned previously, Alexander et al. (1915) did not believe the cod end mesh size would affect the escapement of small fish. The research referenced by Herrington (1935) demonstrated this was not the case in fact, but how and when escapement did occur was still unknown. Many fishermen felt that the fish could not escape while the net was being towed but only during haulback when there was no way on (Davis 1934a). Davis went on to prove that the greater part of escapement occurred while under tow as compared to haulback.

Herrington (1935) quantified his data in terms of a coefficient of selection; a measure of the sharpness of selection. He could not determine whether

the size of the catch affected the selectivity but did determine that the type of twine played an important role. Using European data and his own he found that the selectivity over a range of mesh sizes was approximately constant.

Jensen (1949) identified Todd and Buchanan-Wollaston as some of the first users of the 50% retention point (or release point) in describing selectivity. He further goes on to develop the straight line relationship between 50% release (retention) length (l) and the inner length of the mesh (m):

$$c = \frac{l}{m}$$

He called c the relative releasing effect; today we call it the selection factor. For cod and haddock he found c to be about 3.0.

As the concept of the selection factor came into standard use, researchers were better able to compare their results on a quantitative basis to gain understanding of those things that affect selection. What follows is a summary of this knowledge in regard to gear-related effects as demonstrated by shifts in the value of selection factors.

Experimental design. The most important aspect of determining a selection factor is the actual method employed. There are two basic methods used for studying the selectivity of an otter trawl cod end:

(a) Covered cod-end method. A small-mesh cover is placed over the cod end, loosely fitted, so as to capture all those fish that escape through the cod end meshes. The catches of the cod end and cover are then compared.

(b) Alternate haul method. Two uncovered cod ends are fished; one being much smaller in mesh size than the one for which the selection curve is being determined. The experiment can be conducted by one vessel alternating cod ends either systematically or randomly, by two vessels parallel fishing the

two different meshes, or by one vessel fishing a trouser trawl (a trawl with two cod ends side by side). This latter variant is considered by most as unsatisfactory because of the usual uneven fishing of the two cod ends.

The covered cod-end method is normally considered the best as it takes the least amount of time to obtain good results and is a true measure of what actually escapes the cod end. The risk of using this method is the possibility of the cover "masking" the cod end. This masking effect can consist of the cover physically blocking the cod-end meshes, fish swimming back into the cod end from the cover, fish perceiving the presence of the cover, and effects on the water flow in the cod-end vicinity.

The main advantage of the alternate tow method is that there is no cover bias. For this reason it may more accurately reflect the real selectivity that would be experienced in the related commercial fishery. However there is a disadvantage in that it takes a larger number of tows to collect the data and, once collected, assumptions have to be made on the relative efficiency of the two mesh sizes in order to calculate the selection factor.

Alternate tows usually give higher selection factors than covered tows, probably due to the masking effects of the cover and the increased efficiency of uncovered cod ends on the larger size fish. This phenomenon has mostly been observed with cod and haddock but not with plaice (Saetersdal 1963).

Another aspect of the experimental design that ultimately affects the selection factor is the mesh-measuring method used. The two common methods employed are the use of a vertical gauge, such as a wedge-shaped one inserted into the mesh (Clark 1963), or a longitudinal gauge which looks like a slide caliper. Most of the gauges have a means to exert a known pressure so as to stretch the mesh in a consistent manner. Hodder and May (1965) found that a gauge set for 5.5-kg pressure gave readings 1.04 times higher than one set for

4-kg pressure, thus giving different selection factors. In a more detailed study Beverton and Bedford (1958) discuss variations in measurement between operators and gauge types.

Escapement through component parts of the trawl. Once a fish enters the trawl it may escape through the forward netting sections as well as the cod end. Ellis (1951) discusses some unpublished work of Bowman from 1923 that demonstrated that forward escapement does occur. Clark (1963) found that, compared to the cod end, a relatively small number of haddock escape from the forward parts. Of those that do, he estimated 10% escape through the top belly, 30% through the lower belly, 60% through the lower wings, and none through the square and top wings. Nearly all of the smallest sizes of haddock escaped through the forward parts. Ellis (1963) reports higher escapement from the forward parts for active swimming fish, the lengths of the fish being similar to those escaping through the cod end.

Margetts (1963) found that escapement varied with species and between the two vessels used in his experiment. He hypothesized that this was due to the rigging of the nets and the related fish behavior. He concluded that considerable, and highly variable, quantities of fish can escape from the forward parts of the trawl. For this reason the fish entering the cod end are not necessarily representative of the fish entering the mouth of the trawl.

The above discussion indicates that due to variations in the forward parts of the trawl the selection factor calculated for a particular cod-end mesh size may vary. There are other, more complicated, factors such as the physical condition of the fish entering the trawl and the hydrodynamic relationships between the parts of the trawl that may play an important role (Clark 1960).

There are variations in the cod end itself that affect the selection factor. It has been shown that escapement is mostly from the aft upper portion of the cod end (Beverton 1963; Clark 1963). It is usually this part of the cod end where the meshes have been stretched the most by the weight of the fish when hauled out on deck. When calculating the selection factor this should be taken into account if these stretched meshes differ from the overall mean cod-end mesh size.

Material. It is well established that the type of material a cod end is made of affects its selectivity, but how and why is still a mystery. Two twines may differ in more than a dozen ways, such as material, type of fibre, method of construction, Rtex value, runnage, treatment, elongation properties, strength, flexibility, physical size, etc., etc.

The two most common materials used in the New England fishery are nylon (polyamide) and polypropylene. In comparison fishing these two materials, Bohl (1967a) found that for haddock a polyamide cod end gave selection factors about 7-10% higher than a polypropylene one. He reasoned this was due to the greater extensibility of the polyamide and the fact that the polypropylene had larger knots.

In further studies Bohl (1968) compared three different types of polypropylene twine: splitfibre, continuous, and monofilament. He found no significant difference in their selectivity even though their physical properties were very different. Bohl (1971) also found no significant difference in the selection factor between a "normal" polyamide cod end and an extra-strong one. He also failed to find a correlation between elongation and selectivity.

In general, polyamide gives the highest selection factors, followed by polyester, polypropylene, polyethylene, and manila (Pope et al. 1975).

Speed of tow. Very little is known about the relationship between towing speed and selectivity. This is probably due to the practical difficulty of accurately measuring the speed of the trawl over the bottom and maintaining other parameters constant.

From trawl mensuration work on "36" and "41" Yankee trawls, conducted at the Northeast Fisheries Center, it has been observed that varying towing speed within the range of 2.5-4.0 knots can change the headrope height by several feet. If, for example, the larger fish of a particular species stay further off the bottom than the smaller ones, by varying speed so as to increase headrope height the trawl will select the larger fish. This will ultimately show up in the selection factor calculated for the cod end.

It has also been shown that towing speed affects the hydrodynamics of the trawl. Beverton and Margetts (1963) found that drag increases approximately exponentially with towing speed. They calculated, at speeds of 3-4 knots, drag forces on 53-mm, 69-mm, and 215-mm mesh cod ends of 800 lb, 700 lb, and 150 lb, respectively. There is little doubt that speed affects the tension in the twine of the cod-end meshes and thus probably the selectivity. The Russians, realizing this fact, have studied this approach in their trawl design efforts (Treschev 1963).

Saetersdal (1960) did find a tendency of the selection factors for cod to increase with decreasing speed in the range of 2-3 knots as indicated by the ship's speed log. He did not see this in his haddock data.

Duration of tow. Clark (1963) found that the longer the tow the higher was escapement and thus the selection factor for haddock. The selection factors went from 3.0 for 20-min tows to 3.4 for 80-min tows. Pope and Hall

(1966) didn't find a marked effect, like Clark, for haddock but did see a tendency for higher selection factors in 2-hr tows compared to 1-hr tows.

The general explanation for the above phenomenon is that the longer tow time gives a fish more opportunity to make repeated attempts at escape. As tow time increases so usually does the catch and this may have a counter-balancing effect as discussed in the next section.

Size of catch. Clark (1963) found that for haddock the selection factor decreased with larger catches, the 50% retention point decreasing by as much as 5 cm. McCracken (1963) reported no change in haddock selection factors for catches up to 1,000 fish per tow; however, there was a slight drop in selection factors for larger tows. He couldn't demonstrate this effect for cod. Hodder and May (1964) present data indicating slight decreases in selection factors for cod and haddock with larger catches, but not of a magnitude to affect assessments. There are several papers that report no apparent effects (ICES 1965; Pope and Hall 1966).

There are a number of reasons that have been advanced to explain lower selection factors for larger catches. The fish would have less of a chance to be selected by the larger meshes at the aft end of the cod end. There may be more tension on the meshes making them less flexible, or the meshes may just become blocked. Schooling behavior may even come into play. On the other hand, Pope et al. (1975) report that this effect has only been observed in covered cod-end tows and thus may be an artifact of the method. With larger catches more fish may be swimming back into the cod end from the cover or may be escaping forward of the cover, thus reducing the apparent selectivity.

Vessel and gear. The general opinion of researchers is that the selectivity of cod ends is not appreciably affected directly by the size of the vessel or gear (McCracken 1963; Pope and Hall 1966; Bohl 1967b).

Variation with mesh size. While it is generally assumed that selection factors are relatively constant through a range of mesh sizes, this has been shown not to hold in certain cases. Clark (1963) demonstrated that for silver hake the selection factor increases with mesh size. He reasoned that this was due to a greater flexibility of the larger mesh allowing more fish to force their way through.

Another aspect of selectivity that varies with mesh size is the selection range, the area between the 25% and 75% retention lengths on the selection curve where most of the escapement occurs. The smaller the selection range the sharper the selection. Clark et al. (1958) found that for haddock the selection range for a 75-mm mesh was 4 cm compared to 14 cm for a 150-mm mesh.

As mentioned previously, trawl efficiency apparently increases with cod-end mesh size for most species. Davis (1934) was one of the first to observe this phenomenon for haddock. A larger mesh caught more of the larger size fish. Clark (1963) and Templeman (1963) reported similar results. Evidence exists that indicates this increased efficiency is not related to an increase in speed or ground covered by the larger mesh (Beverton and Margetts 1963; Clark 1963). Beverton and Margetts also indicated that the decrease in drag of a trawl caused by having a larger mesh cod end is relatively insignificant.

Depth and light intensity. In experiments conducted by Pope and Hall (1966) they could find no relationship between selection factor and depth or daylight vs darkness.

Species. The escapement ability, hence the selection factor, can vary considerably from one species to another. The relationship between the shape of the mesh and the shape of the fish is considered important. Roundfish tend to have a cross-sectional shape more nearly matching that of a mesh than

flatfish, and thus tend to have a higher escapement rate for a particular length.

The behavioral response of a particular species to a net is a key factor also. Clark (1963) has demonstrated for silver hake that this species has a lower escape response when compared to other species. In general, for roundfish, when girth is compared to mesh circumference, the majority of the fish that theoretically can fit through do in fact escape.

Draganik and Zobowski (1968) found that haddock which escaped from the cod end, and were retained in the cover, weighed less than fish of equal length retained in the cod end.

What follows is a summary, from the best information available as reported by Holden (1971), of the selection factors of the species with which this report is concerned for New England waters.

Table 1.

Species	Single-twine	
	Polyamide (nylon)	Polypropylene
Cod	3.6	3.5
Haddock	3.4	3.3
Yellowtail	2.3	NA
Winter flounder	NA	NA
American plaice	2.3	NA
Pollock	NA	NA

NA = Not available.

Methods

This study consisted of four series of experiments. Each series had two commercial fishing vessels performing both covered and uncovered cod-end tows. In general, the procedures used were adopted from Pope et al. (1975). All tows were conducted during daylight hours.

Experiment One

This experiment was conducted from the fishing vessels Frances Elizabeth and Christopher Andrew on December 12, 13, and 15, 1977, in inshore waters off Scituate, Massachusetts. On each of three days four tows were made; small- and large-mesh cod ends fished covered and uncovered. The order of the tows was chosen at random and followed by both vessels together, usually within a kilometer of each other. Vessel speed was maintained at 2.0-2.5 knots.

Experiment Two

This experiment was conducted from the fishing vessels Linda B and Metacomet on March 22, 23, 25, and 28, 1978, in inshore waters off Gloucester, Massachusetts. The experiment consisted of four four-tow series by each vessel. The towing order was chosen to minimize cod-end changes during the experiment and thus consisted of the following:

Day 1	Day 2	Day 3	Day 4
Sm mesh	Lg mesh w/cover	Sm mesh w/cover	Lg mesh
Sm mesh w/cover	Lg mesh	Sm mesh	Lg mesh w/cover
Lg mesh	Sm mesh w/cover	Lg mesh w/cover	Sm mesh
Lg mesh w/cover	Sm mesh	Lg mesh	Sm mesh w/cover

Both vessels towed together at 2.5-3.0 knots.

Experiment Three

This experiment was conducted from the fishing vessels Joseph & Lucia II and Joseph & Lucia III, August 13-15, 1978, in the offshore waters of Georges Bank. The experiment consisted of three four-tow series by each vessel. The series was initially chosen, as in Experiment Two, to minimize cod-end changes. However, due to problems with the covers and a large catch of pollock on board (from commercial fishing at night) that had to be landed early, the experiment consisted of the following:

Day 1	Day 2	Day 3 (J&L II)	Day ~~4~~ 3 (J&L III)
Sm mesh w/cover	Sm mesh	Lg mesh	Sm mesh
Sm mesh	Sm mesh w/cover	Sm mesh	Lg mesh
Lg mesh w/cover	Lg mesh	Lg mesh	Sm mesh
Lg mesh	Lg mesh w/cover	Sm mesh	Lg mesh

On the first two days both vessels towed in the same order; on the third day the vessels alternated uncovered tows. The vessels towed within a kilometer of each other at 3.5 knots.

Experiment Four

This experiment was conducted from the fishing vessels Valkyrie and Gen. George S. Patton, October 8-11, 1978, in the waters east of Nantucket Shoals. The experiment consisted of four four-tow series and was performed in the same order as Experiment Two. Vessel speed was maintained at 3.0-3.5 knots.

The sampling techniques were basically the same in all four experiments. At the conclusion of each tow, the respective catches (if a cover was used) were kept segregated. The gear was meticulously checked and net damage and other occurrences that may have affected the validity of the tow were recorded.

Cod-end and cover knots were tied tight and a piece of old webbing was placed in the end to prevent leakage of catch.

After each tow, 30 cod-end meshes were measured along the top of the cod end in one row starting ~~off~~ aft and running forward. They were measured using an ICES longitudinal-type mesh gauge set at 4-kg pressure.

The segregated catches (cod end and cover when used) were worked up separately. Any fish found forward of the cod end were excluded because they may not have undergone the cod-end selection process. The catch was sorted by species into 1- and 2-bushel baskets, weighed, and length-frequency data recorded for each species. In many cases, to save time, the catch was not weighed but all lengths were taken and length-weight equations used to determine catch weight. Subsamples were taken if the catch was too large to handle by this means.

Girth data were also recorded at intervals throughout the experiments.

Mesh Measurements

In 1975, mesh sizes used in the USA Subarea 5 (Gulf of Maine and Georges Bank) cod and haddock fisheries ranged from 110 to 129 mm (4.3 to 5.1 inches), with the majority of cod ends examined (>85%) having mesh sizes from 115 to 124 mm (4.5 to 4.9 inches) (ICNAF 1976). Trawl cod-end mesh sizes used in the 1975 yellowtail flounder fishery ranged from 110 to 139 mm (4.3 to 5.5 inches), with most cod-end meshes between 115 and 129 mm (4.5 and 5.1 inches).

The small mesh size chosen for these experiments was the most commonly used "large" mesh cod end available in New England. It was constructed of #102 braided nylon twine (runnage 73.76 m per kg) and sold as 4.5-inch webbing. The actual average dry-mesh measurement of these cod ends new was

108 mm (4.25 inches). The manufacturer of the webbing said it had been hot-water/steam-treated, accounting for the shrinkage.

The larger mesh size was chosen on the basis of increasing the minimum size of cod to 52 cm (20.5 inches) or an age-at-first-capture of 3 yrs. Using a selection factor of 3.6, this indicated a mesh size of 144 mm (5.7 inches). As no large webbing was available, handmade cod ends of 154 mm (6.06 inches) were constructed to allow for shrinkage.

It was noted that the small "4.5-inch" commercial cod ends used in the experiment were measuring out smaller than what the enforcement statistics were showing for the fishing fleet--4.2 inches vs the fleet's 4.75 inches. It was assumed that this was due to a measuring problem and a mesh-measuring comparison test was conducted. A National Marine Fisheries Service (NMFS) enforcement agent, using a wedge-type gauge, measured the meshes on one of the large experimental cod ends. The same meshes were then measured using the wedge gauge with a 5-kg weight and the ICES gauge set at 4-kg tension. The average readings were 144.8 mm (5.7 inches), 143.0 mm (5.63 inches), and 135.0 mm (5.3 inches), respectively.

Random measurements were then taken on our commercial-sized cod end. The ICES gauge indicated a little over 4 inches. The wedge gauge readings were about 4.5 inches; however, the gauge could be wedged in further to read 4.75 inches or greater (the NMFS enforcement agent said that this is the routine procedure in the field).

Experiment One Mesh Summary. All cod ends were measured dry before starting the experiment. The small cod ends of machine-made webbing initially averaged 108 mm in size but by the second and third day of the experiment averaged 106 mm.

The twine used for the handmade larger cod ends apparently was not heat-treated. The dry measurements averaged 154 mm and during the experiment the mesh averaged 139 mm, a 10% shrinkage rate.

No stretching of the twine was observed during the experiment. There was no consistent variation between meshes of the forward and aft parts of the cod end as would be logically expected with larger catches.

There was a problem measuring the meshes, especially the first day, when the twine started freezing and produced false readings as the twine would not stretch fully. For this reason we rejected the first day's data.

In the small mesh there was a maximum range of 16 mm (0.6 inches) between mesh sizes. In the large mesh the maximum range was 23 mm (0.9 inches). A series of standard error calculations (Appendix C) shows that the 95% confidence limits are within 1 mm of the sample mean.

Experiment Two Mesh Summary. Thirty meshes were measured after each tow; and means, standard deviations, and standard errors calculated (Appendix C). The mean mesh size for the small cod ends on both vessels was practically the same, equalling 99 mm (3.9 inches) when rounded off to the nearest millimeter. These same cod ends were used in the previous Scituate experiment and had averaged 106 mm (4.2 inches).

The large cod ends, which had averaged 139 mm (5.5 inches) during the Scituate experiment, had a mean mesh size during this experiment of 131 mm (5.2 inches). However, the difference between the average mesh size of the two large cod ends, which was 3.5 mm during the Scituate experiment, had grown to 5.3 mm (0.2 inches).

Both mesh gauges were tested against each other by measuring 10 of the same meshes and found to be reading the same. In addition, each gauge was

tested by pulling against a calibrated spring scale and found to be calibrated correctly at 4-kg pressure.

Experiment Three Mesh Summary. Thirty meshes were measured after each tow; and means, standard deviations, and standard errors calculated (Appendix C).

The small cod ends on the Joseph & Lucia II and Joseph & Lucia III had mean mesh sizes of 103.7 mm (4.1 inches) and 109.6 mm (4.3 inches), respectively. These same cod ends averaged 99 mm (3.9 inches) in the second experiment and apparently stretched during the night fishing that preceded the experiment on this trip.

The large cod ends both averaged 140 mm after a 2-hr break-in tow. However, during the experiment the mean mesh sizes were 135.9 mm (5.3 inches) and 140.8 mm (5.5 inches), respectively.

Experiment Four Mesh Summary. Thirty meshes were measured after each tow; and means, standard deviations, and standard errors calculated (Appendix C).

The small cod ends on the Valkyrie and Patton had mean mesh sizes of 108.3 mm (4.3 inches) and 106.0 mm (4.2 inches), respectively.

The large cod end on the Valkyrie averaged 127.4 mm (5.0 inches) and on the Patton averaged 134.6 mm (5.3 inches).

Experiment One Tow Summary. The tows were conducted as described previously. On the first day a number of problems were encountered. The twine started to freeze before mesh measurements could be taken. During Tow 2 a cover float flooded on the Christopher Andrew, causing a marked masking effect. During Tow 3 the Frances Elizabeth caught a large object that caused a door

(otter board) to capsize. Tow 4 was scrubbed because of darkness and the resulting change in fish population available to the gear. For these reasons the first day's data were not used in the overall analysis. All data presented in the Results section, unless otherwise indicated, are for only the second and third days of the experiment. Appendix D presents the basic tow information.

Appendix E is a listing of the catch by weight per tow. The "flounders" category consisted mostly of winter flounder, though some American dabs were included. The "other" category consisted mainly of skates, sculpin, goosefish, crabs, and windowpane flounder.

Experiment Two Tow Summary. The tows were conducted as described previously, the basic tow data being presented in Appendix D. The captains followed normal commercial practice of changing course to follow contours, going around hard bottom (rock piles), and pursuing fish traces on the echo sounder.

There were large variations in catch size and composition between tows, even on a daily basis, making an actual catch comparison between cod-end sizes difficult.

Many tows came up with lost lobster traps and big pieces of waterlogged wood that were in the area due to the large February storm. The Linda B snagged 14 lobster traps in 6 tows, the largest catch being 4 traps. The Metacomet snagged 6 traps in 2 tows, one tow accounting for 5 traps. The traps' condition varied from good to broken up. There were no lobsters in any of the traps nor any good buoys or lines attached. The traps were all found on sand or mud bottom. Most of the traps were caught on the twine forward of the trawl extension. No obvious effect on mesh selectivity was apparent.

The basic catch data are presented in Appendix E, blackback being winter flounder and dabs indicating American plaice. The "other" category consisted mainly of windowpane flounder, sculpin, skates, crabs, and sea ravens. The Metacomet grouped the ocean pout with the "other" category.

There was a small incidental catch of goosefish, lumpfish, wolffish, grey sole, and 12 lobsters. One small halibut, a 15-lb sturgeon, and a 74-cm haddock were caught. Only a few small pollock were caught throughout the study except for Metacomet Tow 11 where 140 pollock (13 kg) were found in the cover, measuring 18-30 cm, the majority being 19-22 cm.

Experiment Three Tow Summary. The tows were conducted as described previously, the basic tow data being presented in Appendix D. The captains followed normal commercial practice of changing course to follow contours, going around hard bottom, and pursuing fish traces on the echo sounder.

The area fished had very few small fish of any species and the catch was quite "clean" or lacking much "trash" fish. There was hardly any fish discarded.

The lack of small fish did not provide for a good data base for the use of the covered-tow method. In addition the covers did not seem to function well. The 72-thread twisted cotton twine that the covers were made of apparently filled up with sand and mud particles, causing the covers to become exceptionally heavy. That and the fact that our catches were large tended to cause a masking of the cod ends. We thus switched to alternate tows exclusively on the third day.

The basic catch data are presented in Appendix E. Whiting are silver hake, dabs are American plaice, and ling are white and red hakes grouped together. There was a small incidental catch of goosefish, wolffish, cusk, *Illex* squid, grey sole, and halibut.

Experiment Four Tow Summary. The tows were conducted as described previously, the basic tow data being presented in Appendix D. The captains followed normal commercial practice of changing course to follow contours, going around hard bottom, and pursuing fish traces on the echo sounder.

During the nonexperimental commercial tows the vessels fished the hard bottom of Nantucket Shoals making good catches of cod and winter flounder. However, they tore up their nets on almost every tow. Since tear-ups invalidate experimental tows, we had to conduct our selectivity experiment on smoother bottom. Here our catches were poor and highly variable. There were very few small fish.

The basic catch data are presented in Appendix E. There were incidental catches of skates, goosefish, sculpins, squid, scallops, herring, lobster, and halibut.

The Patton hardly caught any cod, compared to the Valkyrie, on Tows 5, 7, 14, and 16. In one case it can be attributed to a tear-up (Tow 14) and in one case to a foul-up (Tow 16). Both vessels had numerous small "hangs."

All the problems added together make the data questionable in regard to catch comparisons and selectivity analysis. The reader must keep this in mind when reviewing the following sections.

Results

The results of the four experiments worked up on an independent basis can be found in the Woods Hole laboratory reference series as Laboratory Report Nos. 78-12, 78-24, 78-48, and 78-54 (Smolowitz et al. 1978a, b, c, d). What follows is a summary and synthesis of the four experiments on a species basis.

Cod

The selection factors for cod were determined from each experiment's data and from combined data (Tables 2-5, Figure 2). The range of values of these selection factors falls within the range of those reported by Holden (1971). Assuming the true selection factor lies somewhere between those determined from the covered and alternate tow methods, these experiments confirm the average polyamide selection factor of 3.6 for cod in the North Atlantic reported by Holden (1971).

It is also interesting to note that in each experiment the selection factor determined for the large mesh size was greater than that found for the small mesh. This may indicate a nonlinearity in the selection factor for cod similar to that found by Clark (1963) for silver hake. However, there was no significant difference in selection range between the two mesh sizes which in each case was about 9 cm.

Cod girths were taken randomly throughout the experiment and found to have little variance from the published means for girth-length ratios. The girth-length relationships from Margetts (1957) and later confirmed by Messtorff (1958) are represented by the following equations:

(a) length = natural girth x 1.95

(b) length = (constricted girth x 2.03) + 0.7.

Table 2. Cod selection factor summary.

Experiment	Total no. of fish	Selection factor		
		Sm mesh	Lg mesh	Alternate tow
One	492	3.21	3.31	3.88
Two	2,510	3.19	3.37	3.59
Three	686	-	-	4.00
Four	2,024	3.64	3.74	3.96
Combined	5,712	3.33	3.41	3.80

Most of the sampled girths during this series of experiments fell close to the range indicated by the above two equations (Figure 3).

Table 7 demonstrates an interesting point. For the combined catch during the experiment the large mesh outfished the small mesh, on a weight comparison basis, in all conditions: no discard, 42-cm (16-inch) discard, and 52-cm (20-inch) discard lengths.

Table 3. Cod length frequency distributions and percent retained for the small-mesh (105-mm overall average) covered tows --all vessels.

Length interval (cm)	Numbers caught		% retained
	105 mm	105 mm plus covers	
10-12	0	0	0.0
13-15	1	7	14.3
16-18	2	27	7.4
19-21	5	52	9.6
22-24	3	32	9.4
25-27	7	26	26.9
28-30	17	42	40.5
31-33	42	110	38.2
34-36	104	181	57.5
37-39	206	264	78.0
40-42	203	219	92.7
43-45	220	226	97.3
46-48	153	158	96.8
49-51	79	79	100.0
52-54	109	111	98.2
55-57	74	76	97.4
58-60	69	71	97.2
61-63	46	46	100.0
64-66	75	76	98.7
67-69	81	81	100.0
70-72	82	82	100.0
73-75	86	86	100.0
76-78	79	79	100.0
79-81	53	53	100.0
82-84	33	33	100.0
85-87	20	20	100.0
88-90	12	12	100.0
91-93	21	21	100.0
94-96	8	8	100.0
97-99	12	12	100.0
100-102	9	9	100.0
103-105	11	11	100.0
106-108	4	4	100.0
109-111	3	3	100.0
112-114			
115-117	1	1	100.0
118-120			
121-123			
124-126	1	1	100.0
TOTALS	1,931	2,319	

Table 4. Cod length frequency distributions and percent retained for the large-mesh (135-mm overall average) covered tows --all vessels.

Length interval (cm)	Numbers caught		% retained
	135 mm	135 mm plus covers	
10-12	0	3	-
13-15	0	6	-
16-18	1	25	-
19-21	0	49	-
22-24	1	46	-
25-27	0	44	0.0
28-30	1	50	2.0
31-33	2	71	2.8
34-36	7	71	9.9
37-39	12	61	19.7
40-42	13	60	21.7
43-45	20	59	33.9
46-48	21	32	65.6
49-51	19	26	73.1
52-54	19	26	87.1
55-57	27	31	94.2
58-60	49	52	95.8
61-63	46	48	100.0
64-66	54	54	100.0
67-69	73	73	100.0
70-72	94	94	98.2
73-75	55	56	100.0
76-78	60	60	100.0
79-81	43	43	100.0
82-84	29	29	100.0
85-87	12	12	100.0
88-90	11	11	100.0
91-93	5	5	100.0
94-96	12	12	100.0
97-99	0	0	0.0
100-102	7	7	100.0
103-105	4	4	100.0
106-108	3	3	100.0
109-111	1	1	100.0
135	1	1	100.0
TOTALS	702	1,225	

Table 5. Cod length frequency distributions and percent retained from uncovered cod end tows--all vessels.

Length interval (cm)	Numbers caught (A) 105 mm	Numbers caught (B) 135 mm	$\frac{B}{A}$		% retained by 135 mm $\frac{B}{1.6A} \times 100$
10-12	0	0	0.00		0.0
13-15	0	0	0.00		0.0
16-18	0	0	0.00		0.0
19-21	1	0	0.00		0.0
22-24	1	0	0.00		0.0
25-27	5	0	0.00		0.0
28-30	16	1	0.06		3.9
31-33	31	2	0.06		4.0
34-36	64	4	0.06		3.9
37-39	83	12	0.14		9.0
40-42	124	14	0.11		7.0
43-45	99	22	0.22		13.9
46-48	59	30	0.51		31.8
49-51	60	33	0.55		34.4
52-54	61	55	0.90		56.4
55-57	51	60	1.18		73.5
58-60	61	80	1.31		82.0
61-63	58	88	1.52		94.8
64-66	50	106	2.12		132.5
67-69	58	108	1.86	Avg.	116.4
70-72	63	109	1.73	1.60	108.1
73-75	55	106	1.93		120.4
76-78	44	60	1.36		85.2
79-81	33	49	1.48		92.8
82-84	15	23	1.53		95.4
85-87	17	12	0.71		44.1
88-90	7	12	1.71		107.1
91-93	8	8	1.00		62.5
94-96	8	7	0.88		54.7
97-99	5	1	0.20		12.5
100-102	1	5	5.00		312.5
103-105	3	1	0.33		20.8
106-108	2	5	2.50		156.3
109-111	2	2	1.00		62.5
112-114	1	1	1.00		62.5
121-123	1	0	0.00		-
135	1	0	0.00		-
TOTALS	1,148	1,017			

$$\sum_{55} A = 544 \qquad \sum_{55} B = 843 \qquad \frac{\sum_{55} B}{\sum_{55} A} = 1.55$$

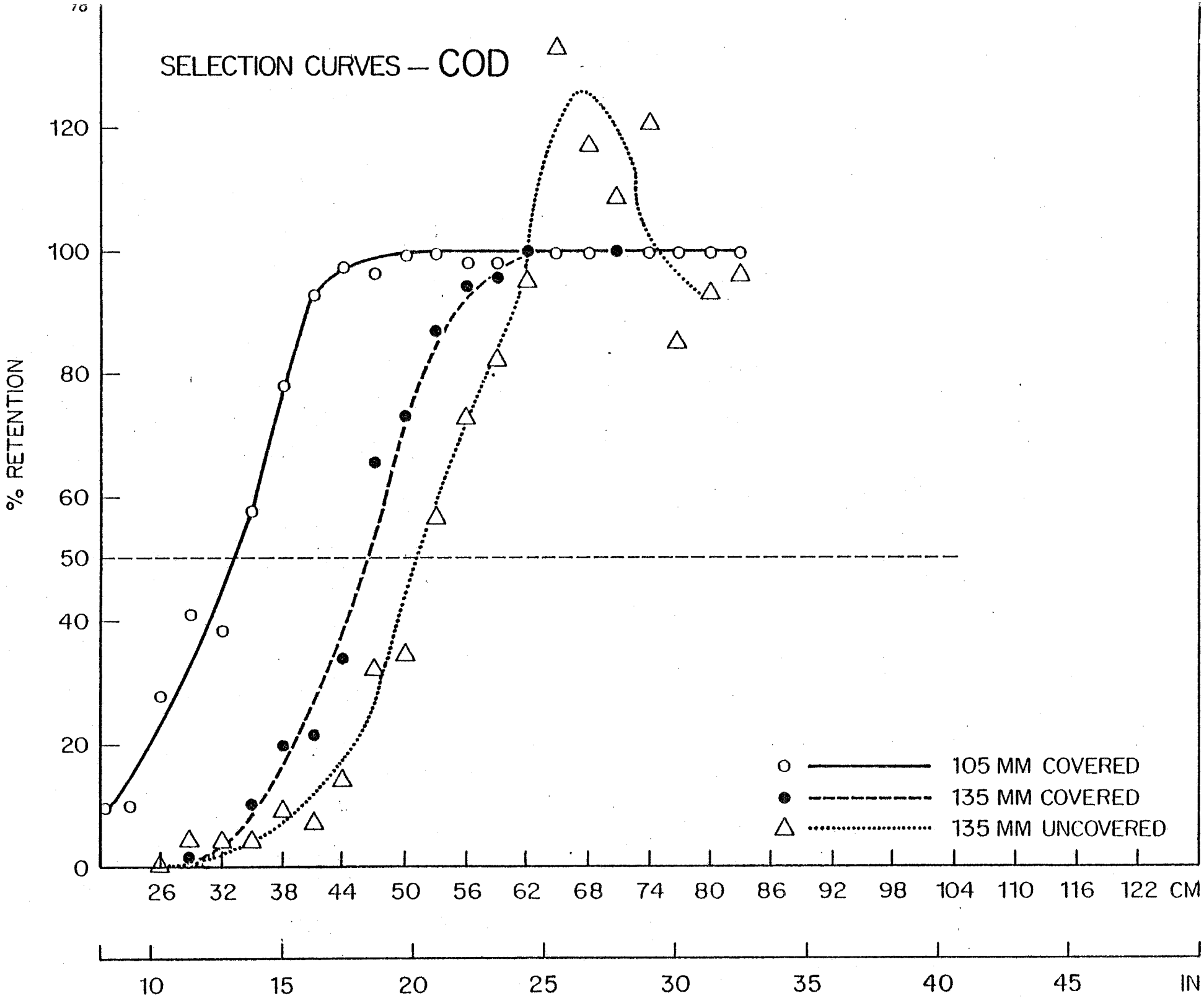

SELECTION CURVES – COD
% RETENTION
120
100
80
60
50
40
20
0
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 CM
10 15 20 25 30 35 40 45 IN
105 MM COVERED
135 MM COVERED
135 MM UNCOVERED

Table 6. Cod length frequency distributions.

Length interval (cm)	Cod ends plus covers			Cod ends only Uncovered tows		Industry
	Overall average	105 mm	135 mm	105 mm	135 mm	
10-12	0.1	0.0	0.2	0.0	0.0	
13-15	0.4	0.3	0.5	0.1	0.0	
16-18	1.6	1.2	2.0	0.1	0.1	
19-21	3.1	2.2	4.0	0.3	0.0	
22-24	2.6	1.4	3.8	0.2	0.1	
25-27	2.4	1.1	3.6	0.4	0.0	
28-30	3.0	1.8	4.1	0.9	0.1	
31-33	5.3	4.7	5.8	2.2	0.3	
34-36	6.8	7.8	5.8	5.4	1.0	
37-39	8.2	11.4	5.0	10.7	1.7	
40-42	7.2	9.4	4.9	10.5	1.9	
43-45	7.3	9.7	4.8	11.4	2.8	
46-48	4.7	6.8	2.6	7.9	3.0	
49-51	2.8	3.4	2.1	4.1	2.7	
52-54	3.5	4.8	2.1	5.6	2.7	
55-57	2.9	3.3	2.5	3.8	3.8	
58-60	3.7	3.1	4.2	3.6	7.0	
61-63	3.0	2.0	3.9	2.4	6.6	
64-66	3.9	3.3	4.4	3.9	7.7	
67-69	4.8	3.5	6.0	4.2	10.4	
70-72	5.6	3.5	7.7	4.2	13.4	
73-75	8.3	3.7	4.6	4.5	7.8	
76-78	8.3	3.4	4.9	4.1	8.5	
79-81	2.9	2.3	3.5	2.7	6.1	
82-84	1.9	1.4	2.4	1.7	4.1	
85-87	1.0	0.9	1.0	1.0	1.7	
88-90	0.7	0.5	0.9	0.6	1.6	
91-93	0.7	0.9	0.4	1.1	0.7	
94-96	0.7	0.3	1.0	0.4	1.7	
97-99	0.5	0.9	0.0	0.6	0.0	
100-102	0.5	0.4	0.6	0.5	1.0	
103-105	0.4	0.5	0.3	0.6	0.6	
106-108	0.3	0.2	0.3	0.2	0.4	
109-111	0.1	0.1	0.1	0.2	0.1	
112-114						
115-117	0.03	0.05		0.1		
118-120						
121-123						
124-126	0.03	0.05		0.1		
137			0.1		0.1	

Table 7. Cod landings.

Length interval (cm)	kg/fish	Small uncovered no.	Small uncovered kg	Large uncovered no.	Large uncovered kg
10-12	0.03				
13-15	0.04				
16-18	0.04				
19-21	0.04	1	0.04		
22-24	0.09	1	0.09		
25-27	0.13	5	0.7		
28-30	0.22	16	3.5	1	0.2
31-33	0.34	31	10.5	2	0.7
34-36	0.45	64	28.8	4	1.8
37-39	0.58	83	48.1	12	7.0
40-42	0.67	124	83.1	14	9.4
43-45	0.85	99	84.2	22	18.7
46-48	1.03	59	60.8	30	30.9
49-51	1.21	60	72.6	33	39.9
52-54	1.44	61	87.8	55	79.2
55-57	1.71	51	87.2	60	102.6
58-60	2.07	61	126.3	80	165.6
61-63	2.30	58	133.4	88	202.4
64-66	2.66	50	133.0	106	282.0
67-69	3.02	58	175.2	108	326.2
70-72	3.38	63	212.9	109	368.4
73-75	4.10	55	225.5	106	434.6
76-78	4.50	44	198.0	60	270.0
79-81	5.40	33	178.2	49	264.6
82-84	5.90	15	88.5	23	135.7
85-87	6.30	17	107.1	12	75.6
88-90	7.20	7	50.4	12	86.4
91-93	7.70	8	61.6	8	61.6
94-96	8.60	8	68.8	7	60.2
97-99	9.90	5	49.5	1	9.9
100-102	10.80	1	10.8	5	54.0
103-105	11.70	3	35.1	1	11.7
106-108	12.60	2	25.2	5	63.0
109-111	13.50	2	27.0	2	27.0
112-114	14.40	1	14.4	1	14.4
121-123	19.40	1	19.4		
135	29.70	1	29.7		
TOTALS		1,148	2,537.4	1,016	3,203.7
Landings (discard ≤42 cm)		823	2,362.6	983	3,184.6
Landings (discard <52 cm)		605	2,145.0	898	3,095.1

Haddock

The tables and graphs in this section represent the data from 24 tows made during the third experiment. The total catch consisted of 4,463 haddock.

Table shows the length frequency distributions of the haddock during the experiment. Looking at the "cod ends and covers" distributions ~~we~~ it can be seen that both vessels and both size cod ends sampled the same basic populations. This is further demonstrated in Figure .

Reviewing the "cod ends only" distributions ~~we can detect "masking"~~ "masking" can be detected when comparing the 138-mm covered cod ends to the 138-mm uncovered; a higher percentage of smaller fish were caught in the former.

Selection data for the 107-mm covered cod-end tows are given in Table and the corresponding selection curve, drawn by eye, is shown in Figure . The 50% retention length of approximately 34 cm (13.4 inches) gives a selection factor of 3.17.

Selection data for the 138-mm covered cod-end tows are given in Table , and the corresponding selection curve is shown in Figure . The 50% retention length of approximately 42 cm (16.5 inches) gives a selection factor of 3.04.

Selection data for the 107-mm and 138-mm uncovered tows are given in Table . (For a detailed explanation of ~~our~~ the methodology refer to Pope et al. 1975.) From this method, a 50% retention length of 48 cm (18.9 inches) is obtained for the 138-mm cod end which gives a selection factor of 3.47.

Figure demonstrates the portion of the available population, represented by the cod-ends-plus-covers curve, that each cod end selects. ~~We can see that~~ Very few fish existed below the selection range of the 107-mm cod ends. As expected, the larger cod end caught fewer of the smaller fish.

A review of the length frequency distributions shows that the larger cod end caught more of the larger-size fish than the small cod end. ~~A full~~

~~discussion of this commonly seen phenomenon will be in the final report of the mesh studies~~. Table shows the effect of this increased efficiency in higher landings of the large cod end.

Table . Length frequency distributions (%)--haddock.

Length interval (cm)	Cod ends and covers					Cod ends only			
	Overall average	107 mm	138 mm	JOSEPH & LUCIA II	JOSEPH & LUCIA III	107 mm covered	107 mm uncovered	138 mm covered	138 mm uncovered
28-30	0.1	0.2		0.1		0.2			
31-33	0.2	0.4	0.1	0.1	0.3	0.0		0.1	
34-36	0.3	0.6	0.2	0.5	0.1	0.4	0.1	0.0	
37-39	1.2	1.5	1.1	1.6	0.9	0.9	0.9	0.2	
40-42	4.7	5.6	4.2	5.0	4.3	5.3	3.5	2.5	0.6
43-45	5.7	5.9	5.6	6.2	5.2	6.0	6.2	3.9	1.2
46-48	4.5	4.1	4.7	4.5	4.5	4.1	5.9	4.4	2.8
49-51	12.7	13.5	12.2	13.9	11.5	13.6	12.9	12.1	10.7
52-54	26.2	27.2	25.6	24.4	27.7	27.7	26.2	26.7	28.8
55-57	28.2	25.4	29.7	28.4	28.0	25.8	26.9	31.9	34.3
58-60	12.8	11.1	13.7	11.7	13.7	11.3	13.1	14.9	15.8
61-63	2.3	2.6	2.1	2.1	2.4	2.6	2.5	2.3	4.0
64-66	0.6	0.6	0.6	0.5	0.6	0.6	0.9	0.7	0.8
67-69	0.3	0.4	0.3	0.4	0.3	0.4	0.2	0.3	0.1
70-72	0.3	0.7		0.3	0.3	0.8	0.3		0.3
73-75	0.0	0.0		0.0		0.0	0.2		0.3
76-78	0.1	0.4		0.3		0.4	0.1		0.3
79-81									0.0
82-84									0.1
TOTALS	1,547	540	1,007	761	786	531	1,372	915	1,544

Figure

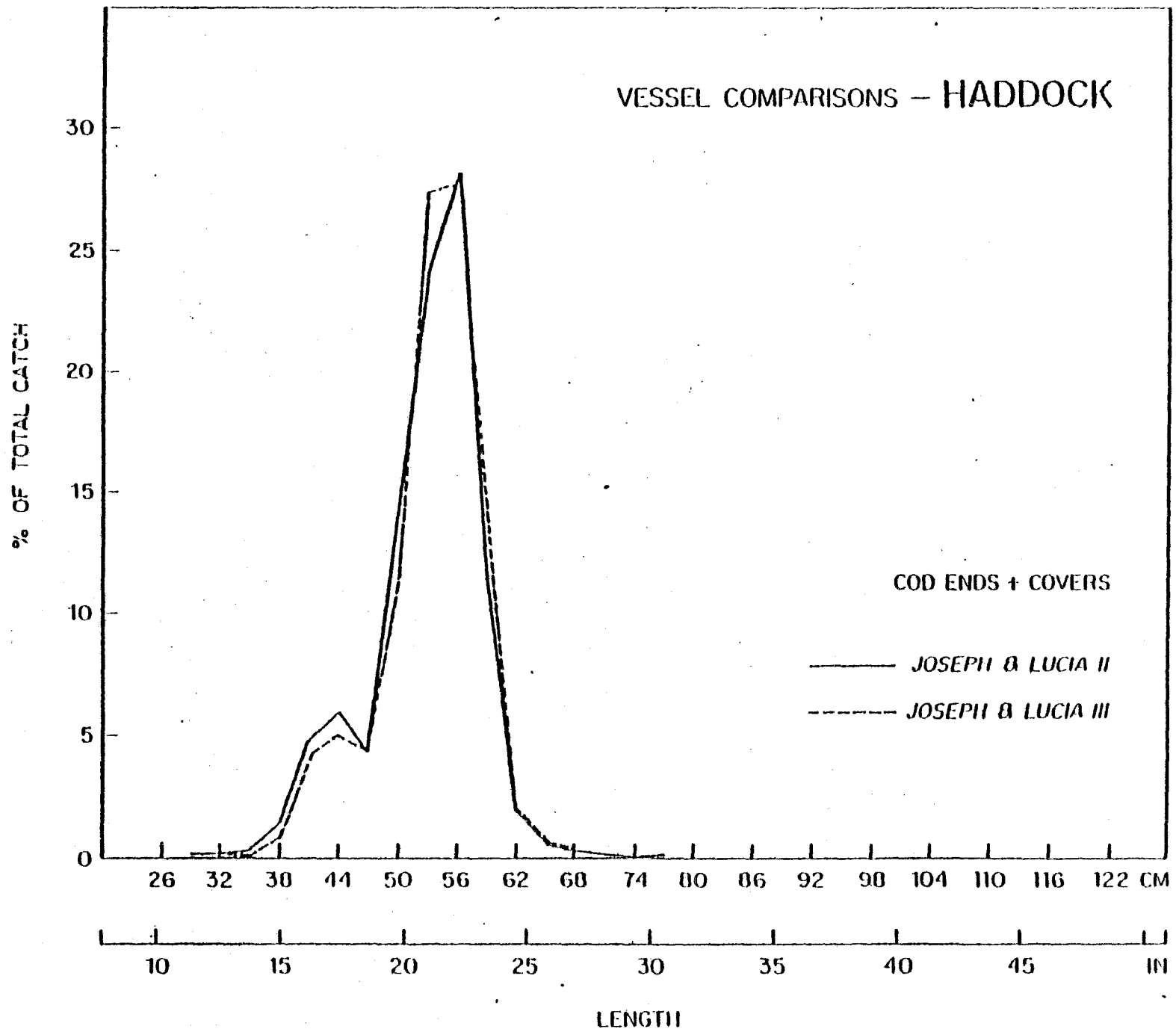

VESSEL COMPARISONS – HADDOCK
% OF TOTAL CATCH
30
25
20
15
10
5
0
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 CM
10 15 20 25 30 35 40 45 IN
LENGTH
COD ENDS + COVERS
JOSEPH & LUCIA II
JOSEPH & LUCIA III

Table . Haddock length frequency distributions and percent retained for 107-mm cod end covered tows--both vessels.

Length interval (cm)	Numbers caught		% retained
	107 mm	107 mm plus covers	
28-30	1	1	100.0
31-33	0	2	0.0
34-36	2	3	66.6
37-39	5	8	62.5
40-42	28	30	93.3
43-45	32	32	100.0
46-48	22	22	100.0
49-51	72	73	98.6
52-54	147	147	100.0
55-57	137	137	100.0
58-60	60	60	100.0
61-63	14	14	100.0
64-66	3	3	100.0
67-69	2	2	100.0
70-72	4	4	100.0
73-75	0	0	100.0
76-78	2	2	100.0
TOTALS	531	540	

Table . Haddock length frequency distributions and percent retained for 138-mm cod end covered tows--both vessels.

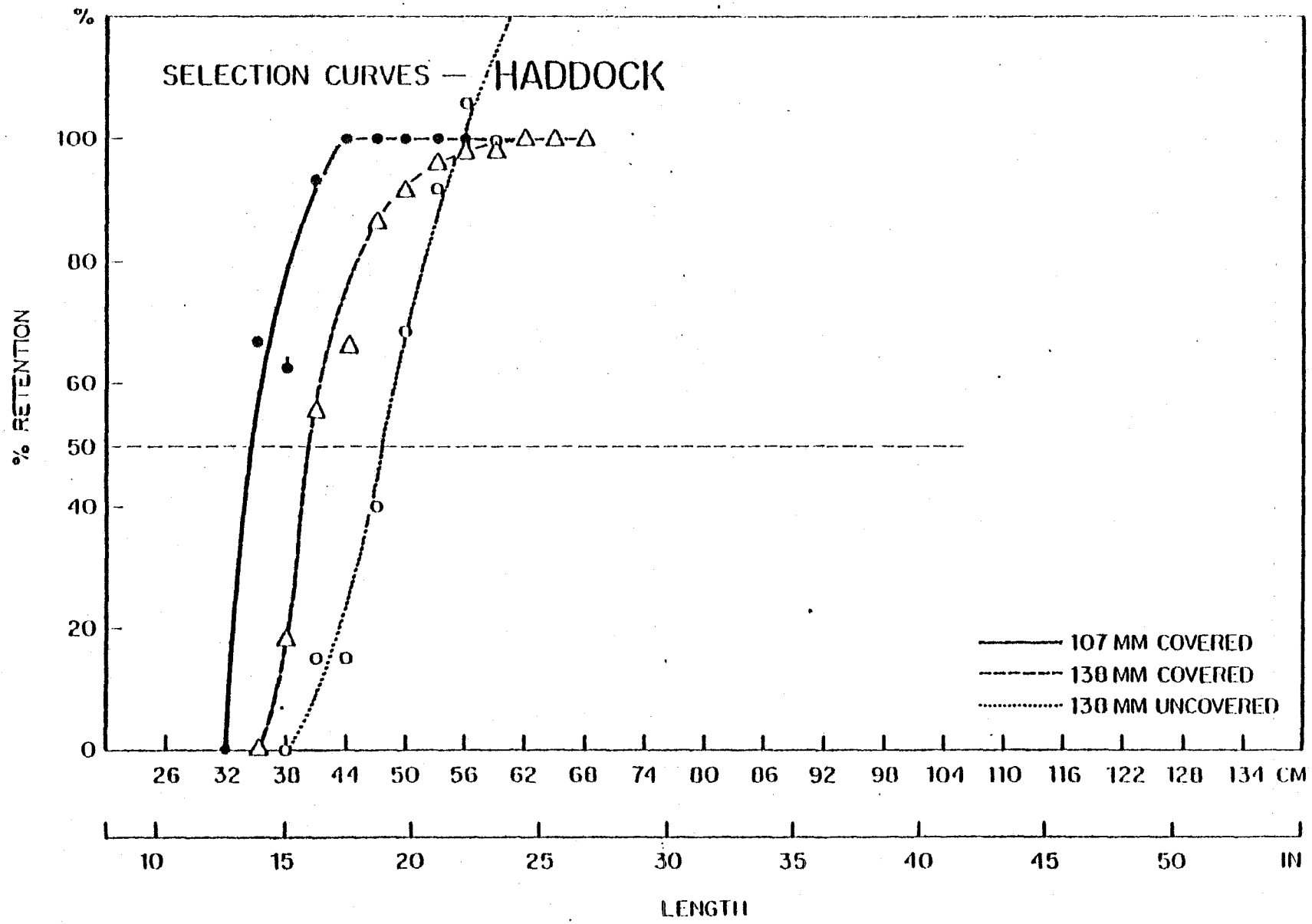
Length interval (cm)	Numbers caught		% retained
	138 mm	138 mm plus covers	
31-33	1	1	100.0
34-36	0	2	0.0
37-39	2	11	18.2
40-42	23	42	54.8
43-45	36	56	64.3
46-48	40	47	85.1
49-51	111	123	90.2
52-54	244	258	94.6
55-57	292	299	97.7
58-60	136	138	98.6
61-63	21	21	100.0
64-66	6	6	100.0
67-69	3	3	100.0
TOTALS	915	1,007	

Table . Haddock length frequency distributions and percent retained for the 138-mm uncovered cod end compared with the 107-mm uncovered cod end--both vessels.

Length interval (cm)	Numbers caught (A) 107 mm	Numbers caught (B) 138 mm	$\frac{B}{A}$		$\frac{B}{1.37A} \times 100$
34-36	1	0	0.00		0.0
37-39	13	0	0.00		0.0
40-42	48	10	0.21		15.2
43-45	85	18	0.21		15.5
46-48	81	44	0.54		39.7
49-51	177	165	0.93		68.0
52-54	360	445	1.24		90.2
55-57	369	529	1.43	Avg.	104.6
58-60	180	244	1.35	1.38	98.9
61-63	34	61	1.79		131.0
64-66	12	13	1.08		79.1
67-69	3	2	0.67		48.7
70-72	4	4	1.00		73.0
73-75	3	4	1.34		97.3
76-78	2	0	-		-
79-81	0	1	-		-
TOTALS	1,372	1,544			

$$\sum_{52}^{81} A = 967 \qquad \sum_{52}^{81} B = 1{,}303 \qquad \frac{B}{A} = 1.35$$

Figure


SELECTION CURVES — HADDOCK
%
100
80
60
50
40
20
0
% RETENTION
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 128 134 CM
10 15 20 25 30 35 40 45 50 IN
LENGTH
107 MM COVERED
138 MM COVERED
138 MM UNCOVERED

Figure

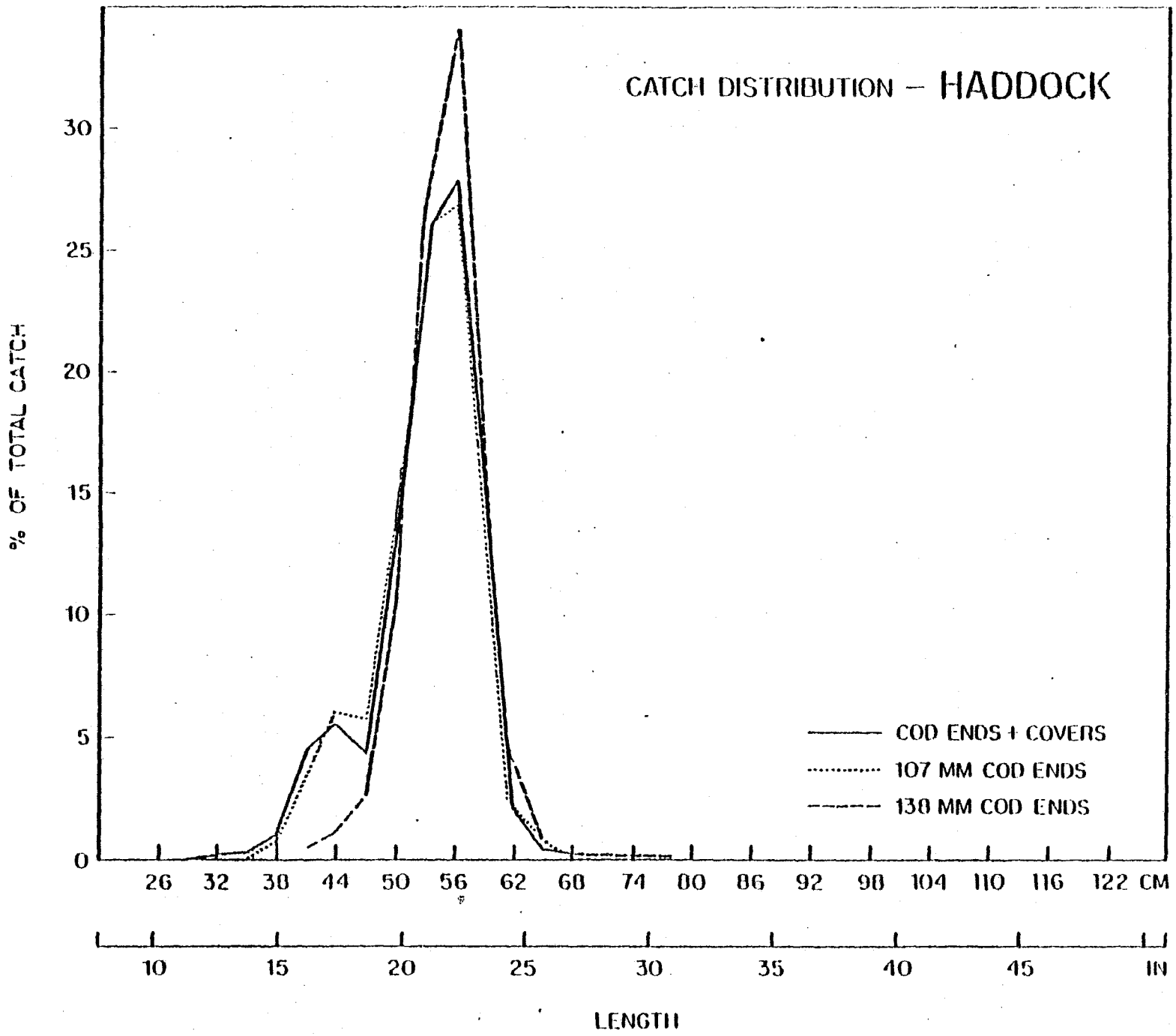

CATCH DISTRIBUTION – HADDOCK
% OF TOTAL CATCH
30
25
20
15
10
5
0
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 CM
10 15 20 25 30 35 40 45 IN
LENGTH
COD ENDS + COVERS
107 MM COD ENDS
138 MM COD ENDS

Table . Weights of haddock by 3-cm groups.

Length interval (cm)	Kg/fish	Small uncovered		Small covered		Large uncovered		Large covered	
		No.	Kg	No.	Kg	No.	Kg	No.	Kg
10-12	0.013								
13-15	0.027								
16-18	0.048								
19-21	0.08								
22-24	0.12								
25-27	0.18								
28-30	0.25			1	0.3				
31-33	0.34			0	0			1	0.3
34-36	0.44	1	0.4	2	0.9			0	0
37-39	0.57	13	7.4	5	2.9			2	1.1
40-42	0.72	48	34.6	28	20.2	10	7.2	23	16.6
43-45	0.90	85	76.5	32	28.8	18	16.2	36	32.4
46-48	1.10	81	89.1	22	24.2	44	48.4	40	44.0
49-51	1.32	177	233.6	72	95.0	165	217.8	111	146.5
52-54	1.58	360	568.8	147	232.3	445	703.1	244	385.5
55-57	1.88	369	693.7	137	257.6	529	994.5	292	549.0
58-60	2.20	180	396.0	60	132.0	244	536.8	136	299.2
61-63	2.56	34	87.0	14	35.8	61	156.2	21	53.8
64-66	2.96	12	35.5	3	8.9	13	38.5	6	17.8
67-69	3.40	3	10.2	2	6.8	2	6.8	3	10.2
70-72	3.88	4	15.5	4	15.5	4	15.5		
73-75	4.41	3	13.2	0	0	4	17.6		
76-78	4.98	2	10.0	2	10.0	4	19.9		
79-81	5.60					0	0		
82-84	6.27					1	6.3		
85-87	6.99								
88-90	7.77								
		1,372	2,271.5	531	871.2	1,544	2,784.8	915	1,556.4
Total weight -			2,271.5		871.2		2,784.8		1,556.4
Landings (discard <52) -			1,829.9		698.9		2,495.2		1,315.5
% discard -			19.4		19.8		10.4		15.5

Yellowtail flounder

These results are based on catch data from Experiments One, Two, and Four.

Table summarizes the selection factors determined during this series of experiments. The alternate tow selection factors are in close agreement with those found by Lux (1968). Assuming the real selectivity lies between the two methods used, 2.25 is a fair choice for the selection factor. Figure shows the selection curves determined from the combined data (Tables to). The 25-75% selection ranges found throughout the experiment varied from 3 to 6 cms. Again, as with the cod data, the selection factors for the small covered mesh are lower than those determined for the larger mesh.

It should be noted that a comparison of the two large-mesh selection curves determined by the two methods used is not strictly valid. This is due to the fact that the uncovered selection curve was derived by comparing the large-mesh uncovered cod ends with the small-mesh uncovered cod ends and the covered selection curve was derived by comparing the large-mesh covered cod ends with the 50-mm covers. In the first case the retention percentages will be affected by the selectivity of the small-mesh cod ends, this occurring where the selection process overlaps (in this case about 17 to 27 cm). The degree of inaccuracy introduced was checked by adjusting the large-mesh uncovered retention percentages with the small-mesh covered retention percentages and was found to be small.

Continuing in the same vein, if all four types of tows (small and large, covered and uncovered) were compared to the same base (covered cod ends plus covers) and adjusted on a numbers-per-tow basis, a comparison could be made between the two mesh sizes that might indicate some degree of relative efficiency. A larger number of tows than performed during this series of experiments is required to do this with any degree of confidence.

An analysis of combined landings and discard (Table) indicates a smaller catch with the larger mesh. From observations made during the experiments, it was noted that the majority of fish 30 cm (11.8 inches) and smaller were discarded. (New Bedford landings data show very few fish being landed under 30 cm.) This is a lower cull point than in the past. Hennemuth and Lux (1970) reported a cull midpoint for yellowtail by the commercial fleet of 34 cm (13.5 inches).

Using 30 cm as the cull point, the data from this series of experiments indicates a 36.9% discard rate (by number of fish) for a 4-inch mesh. A 5¼-inch mesh reduces this discard by 75% when compared on a weight basis.

Table . Yellowtail flounder selection factor summary.

Experiment	Total no. of fish	Selection factor		
		Sm mesh	Lg mesh	Alternate tow
One	3,581	2.07	2.16	2.37
Two	8,881	2.08	2.09	2.30
Four	321	-	-	-
Combined[1]	12,783	2.16	2.18	2.29

~~[1]Combined also contains data from Experiment Four.~~

Table . Yellowtail flounder length frequency distributions and percent retained for the small-mesh (102-mm overall average) covered tows--six vessels.

Length interval (cm)	Numbers caught		% retained
	102 mm	102 mm plus covers	
10-12	0	2	0.0
13-15	0	36	0.0
16-18	14	185	7.6
19-21	78	335	23.3
22-24	242	333	72.7
25-27	274	286	95.8
28-30	216	216	100.0
31-33	491	496	99.0
34-36	715	720	99.3
37-39	523	524	99.8
40-42	282	284	99.3
43-45	182	182	100.0
46-48	59	52	100.0
49-51	9	9	100.0
52-54	4	4	100.0
55-57	2	2	100.0
TOTALS	3,088	3,670	

Table . Yellowtail flounder length frequency distributions and percent retained for the large-mesh (133-mm overall average) covered tows--six vessels.

Length interval (cm)	Numbers caught		% retained
	133 mm	133 mm plus covers	
10-12	0	0	0.0
13-15	1	25	4.0
16-18	13	221	5.9
19-21	26	460	5.7
22-24	62	460	13.5
25-27	109	316	34.5
28-30	132	243	54.3
31-33	335	392	85.5
34-36	532	550	96.7
37-39	319	323	98.8
40-42	199	199	100.0
43-45	118	118	100,0
46-48	46	46	100.0
49-51	9	9	100.0
52-54	0	0	-

Table . Yellowtail flounder length frequency distributions and percent retained from uncovered cod end tows--six vessels.

Length interval (cm)	Numbers caught (A) 102 mm	Numbers caught (B) 133 mm	$\frac{B}{A}$		% retained by 133 mm $\frac{B}{0.82A} \times 100$
10-12	0	0	0.00		0.0
13-15	0	1	0.00		0.0
16-18	15	3	0.20		24.4
19-21	118	2	0.02		2.1
22-24	460	27	0.06		7.2
25-27	430	68	0.16		19.3
28-30	395	94	0.24		29.0
31-33	567	301	0.53		64.7
34-36	833	551	0.66		81.0
37-39	513	444	0.87	Avg. 0.82	105.5
40-42	295	223	0.76		92.2
43-45	146	144	0.99		120.3
46-48	46	38	0.83		100.7
49-51	20	11	0.55		67.1
52-54	2	2	1.00		121.6
55-57	2	0	0.00		-
TOTALS	3,842	1,909			

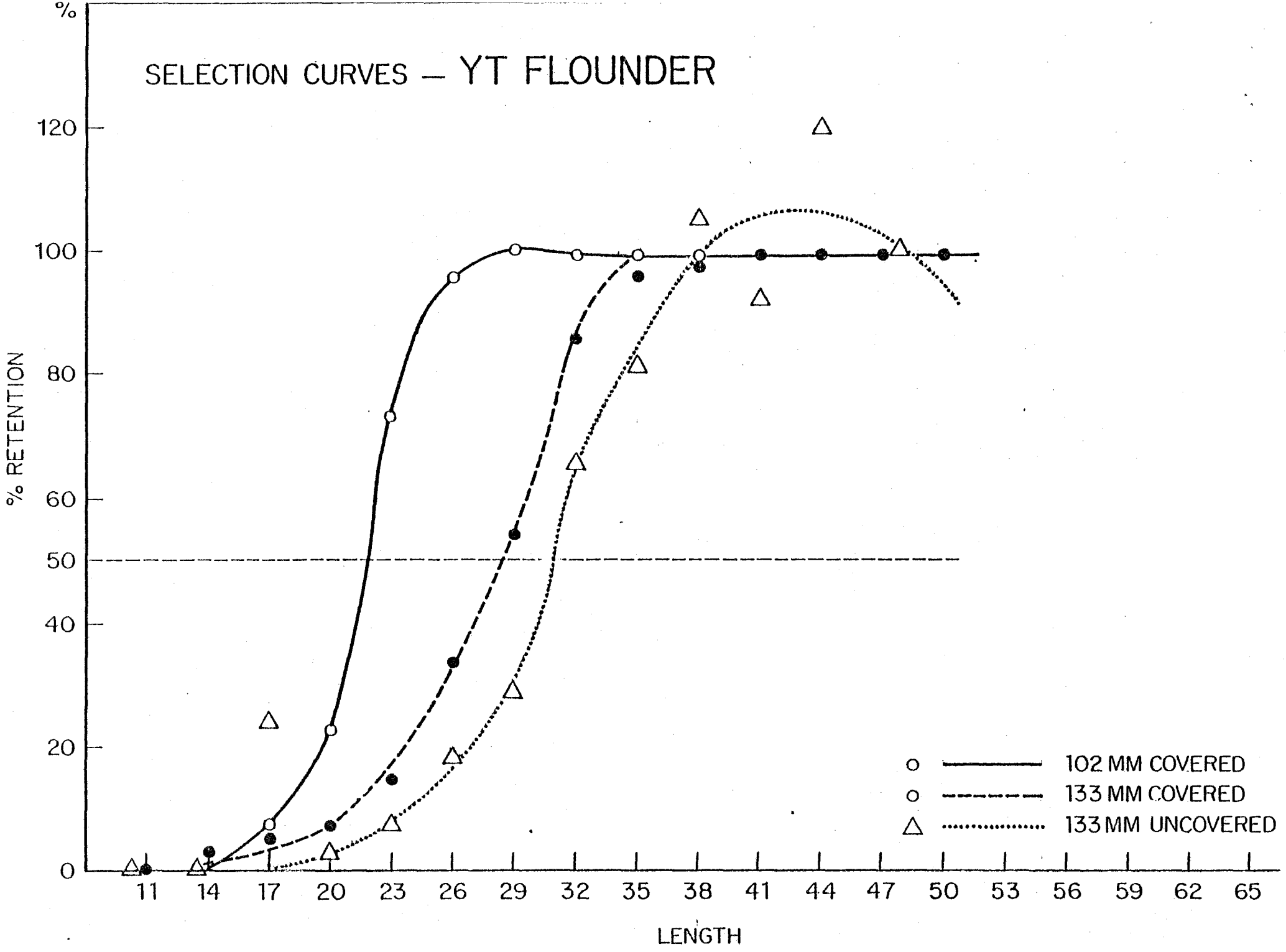

SELECTION CURVES — YT FLOUNDER
%
120
100
80
60
50
40
20
0
% RETENTION
11
14
17
20
23
26
29
32
35
38
41
44
47
50
53
56
59
62
65
LENGTH
102 MM COVERED
133 MM COVERED
133 MM UNCOVERED

Table . Yellowtail flounder length frequency distributions.

Length interval (cm)	Cod ends plus covers			Cod ends only Uncovered tows		Industry
	Overall average	102 mm	133 mm	102 mm	133 mm	
10-12	0.05	0.1	0.0	0.0	0.0	
13-15	0.9	1.0	0.7	0.0	0.1	
16-18	5.8	5.0	6.6	0.5	0.7	
19-21	11.4	9.1	13.7	2.5	1.4	
22-24	11.4	9.1	13.7	7.8	3.3	
25-27	8.6	7.8	9.4	8.9	5.7	
28-30	6.6	5.9	7.2	7.0	6.9	
31-33	12.6	13.5	11.7	15.9	17.6	
34-36	18.0	19.6	16.4	23.2	28.0	
37-39	12.0	14.3	9.6	16.9	16.8	
40-42	6.8	7.7	5.9	9.1	10.5	
43-45	4.3	5.0	3.5	5.9	6.2	
46-48	1.4	1.4	1.4	1.9	2.4	
49-51	0.25	0.2	0.3	0.3	0.5	
52-54	0.05	0.1	0.0	0.1	0.0	
55-57	0.05	0.1		0.1		
TOTALS		3,670	3,362	3,088	1,901	

Table . Yellowtail flounder landings and discard.

Length interval (cm)	kg/fish	Small uncovered		Large uncovered	
		no.	kg	no.	kg
10-12		0	0.0	0	0.0
13-15	0.02	0	0.0	1	0.02
16-18	0.04	15	0.6	3	0.1
19-21	0.07	118	8.3	2	0.1
22-24	0.09	460	41.4	27	2.4
25-27	0.13	430	55.9	68	8.8
28-30	0.22	395	86.9	94	20.7
31-33	0.31	567	175.8	301	93.3
34-36	0.41	833	341.5	551	225.9
37-39	0.59	513	302.7	444	262.0
40-42	0.68	295	200.6	223	151.6
43-45	0.86	146	125.6	144	123.8
46-48	1.04	46	47.8	38	39.5
49-51	1.17	20	23.4	11	12.9
52-54	1.44	2	2.9	2	2.9
55-57	1.67	2	3.3	0	0.0
58-60	2.14				
TOTALS		3,842	1,416.7	1,909	944.0
Landings (discard ≤30 cm)			1,223.6		911.9
Discard		1,418	193.1	195	32.14
% discard		36.9	13.6	10.2	3.4

% reduction in discard between mesh sizes: 75% by weight.

Pollock

These results are based on a catch of 1,118 pollock made during Experiment Three. (It should be noted that at night in the same area catches of 14,000 lb of pollock in 2-3-hr tows were common.) Table and Figure indicate both vessels fished the same basic population distribution.

The covered-tow method could not be used to determine the selection of the small cod end due to lack of small fish.

Selection data for the 138-mm covered cod-end tows are given in Table and Figure . The 50% retention length of about 45 cm (17.7 inches) gives a selection factor of 3.26.

Selection data for the 107-mm and 138-mm uncovered tows are given in Table and Figure . A 50% retention length of 46 cm (18.1 inches) is obtained for the 138-mm cod end which gives a selection factor of 3.33.

It is interesting to note that the same large covered tows showed a definite masking effect in regard to haddock during this experiment but it did not show up for pollock. Figure shows the larger cod end catching fewer small fish.

Figure

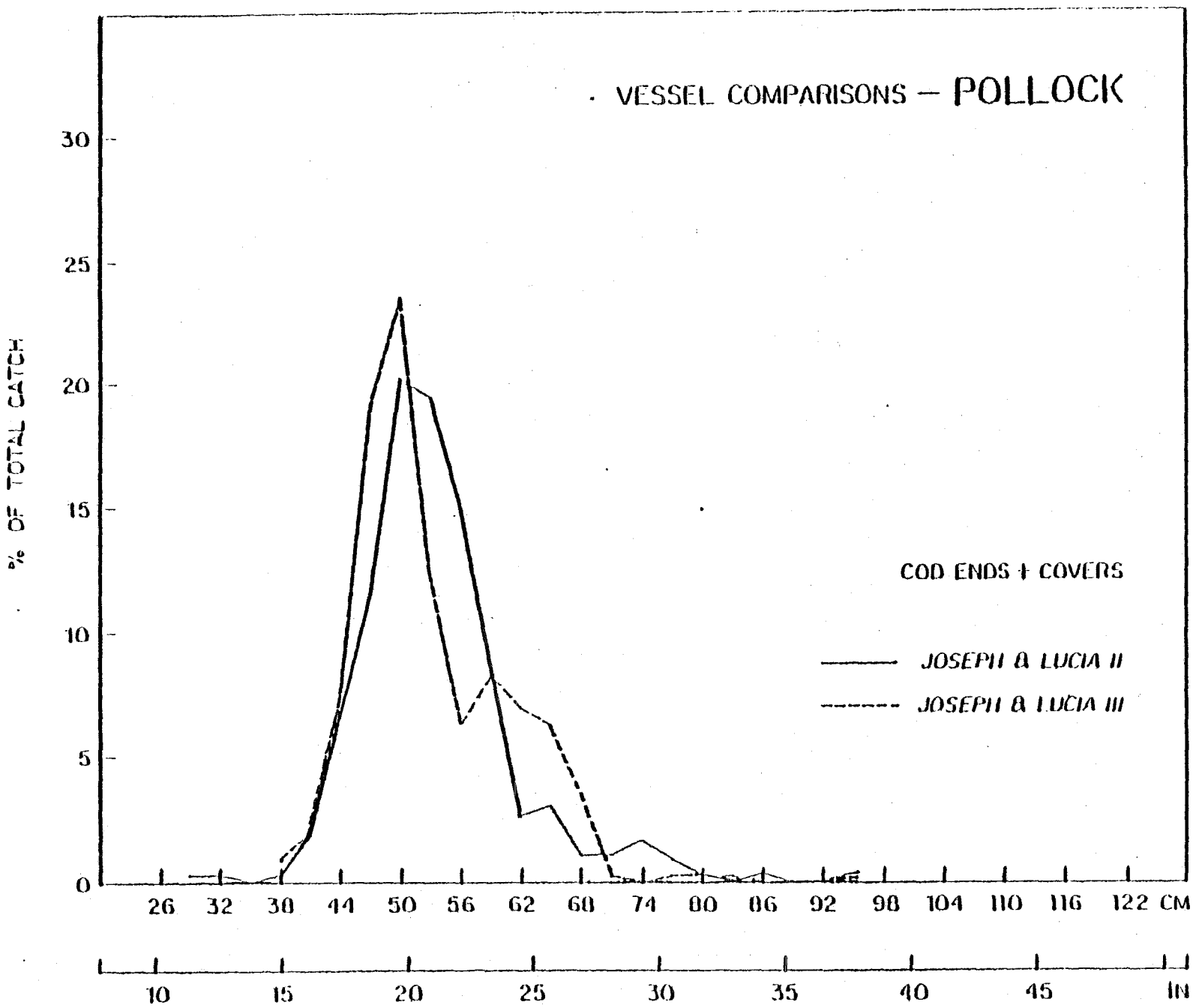

VESSEL COMPARISONS – POLLOCK
% OF TOTAL CATCH
30
25
20
15
10
5
0
COD ENDS + COVERS
JOSEPH & LUCIA II
JOSEPH & LUCIA III
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 CM
10 15 20 25 30 35 40 45 IN

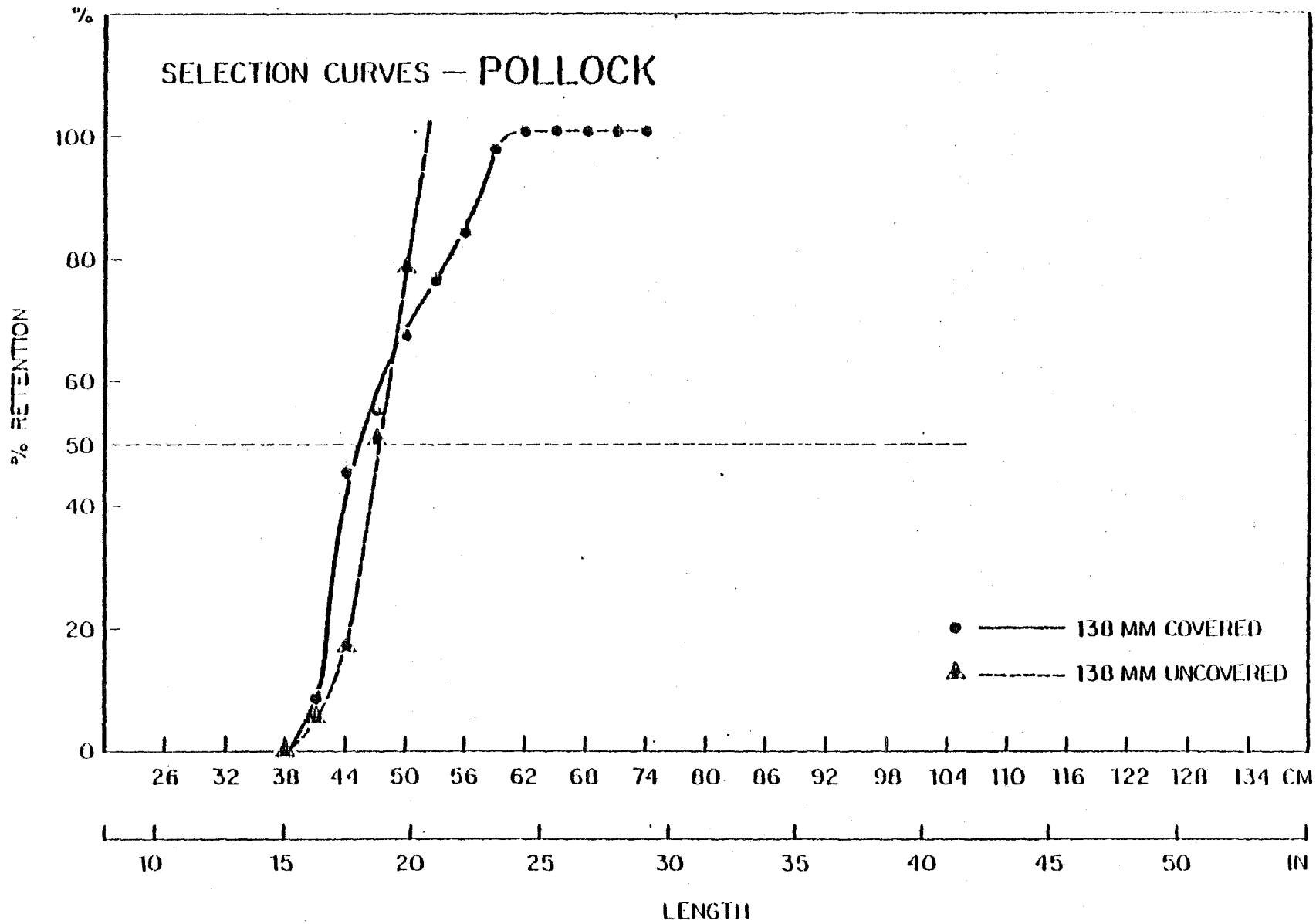
Table . Pollock length frequency distributions and percent retained for 138-mm cod end covered tows--both vessels.

Length interval (cm)	Numbers caught		% retained
	138 mm	138 mm plus covers	
37-39	0	2	0.0
40-42	1	11	9.1
43-45	17	37	45.9
46-48	48	87	55.2
49-51	78	115	67.8
52-54	64	83	77.1
55-57	42	50	84.0
58-60	47	48	97.9
61-63	24	24	100.0
64-66	28	28	100.0
67-69	15	15	100.0
70-72	2	2	100.0
73-75	2	2	100.0
76-78	0	0	100.0
79-81	1	1	100.0
82-84	0	0	100.0
85-87	1	1	100.0
TOTALS	370	506	

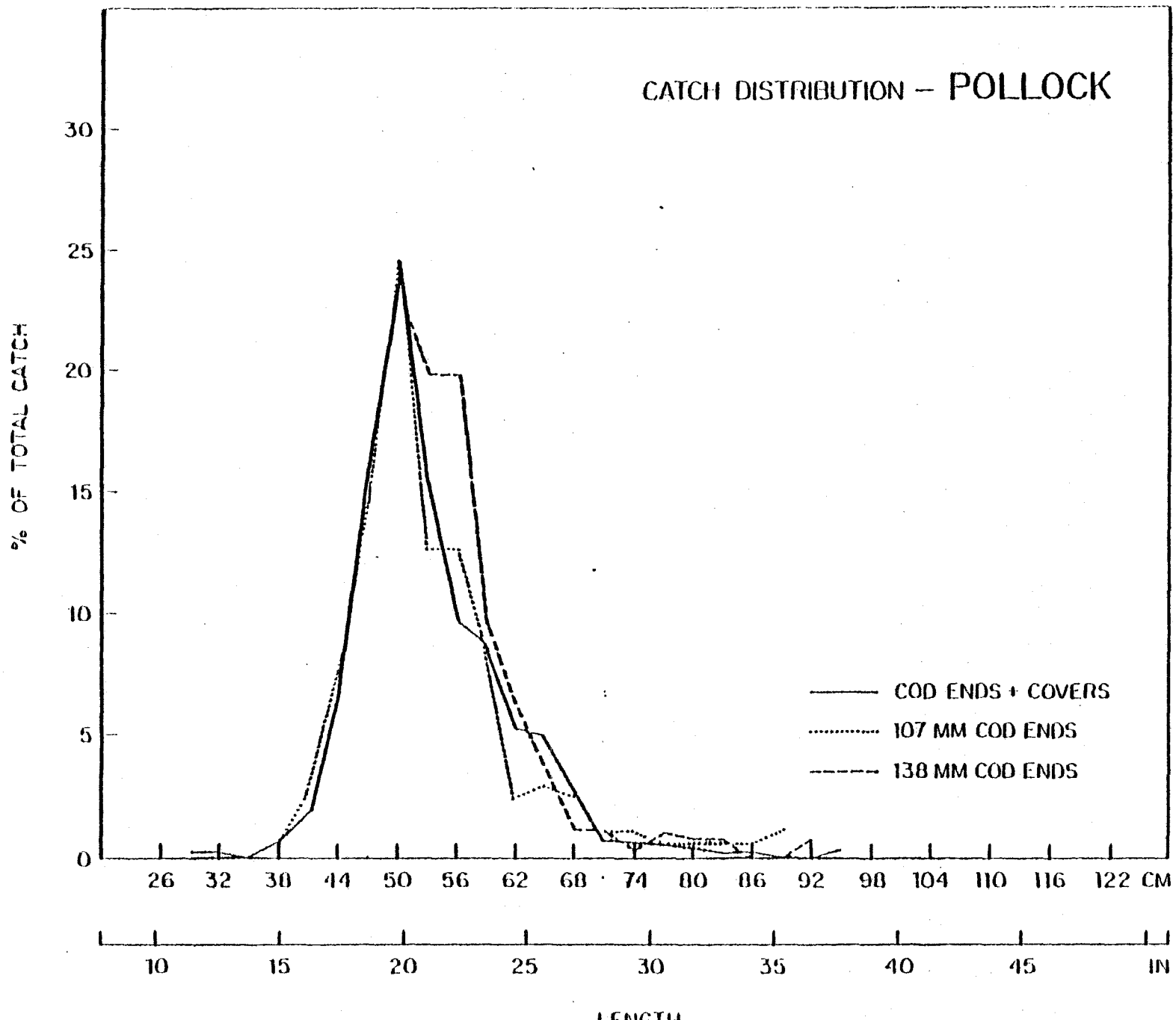
Table . Pollock length frequency distributions and percent retained for the 138-mm uncovered cod end compared with the 107-mm uncovered cod end--both vessels.

Length interval (cm)	Numbers caught (A) 107 mm	Numbers caught (B) 138 mm	$\frac{B}{A}$		$\frac{B}{2.9A} \times 100$
37-39	1	0	0.00		0.0
40-42	5	1	0.20		6.9
43-45	13	7	0.54		18.6
46-48	23	34	1.48		51.0
49-51	40	91	2.28		78.4
52-54	21	78	3.71		128.1
55-57	21	78	3.71		128.1
58-60	15	38	2.53	Avg. 2.94	87.4
61-63	4	24	6.00		206.9
64-66	5	15	3.00		103.4
67-69	4	5	1.25		43.1
70-72	2	5	2.50		86.2
73-75	2	1	0.50		17.2
76-78	1	4	4.00		137.9
79-81	1	3	3.00		103.4
82-84	1	3	3.00		103.4
85-87	1	0	-		
88-90	2	0	-		
91-93	0	3	-		
94-96	0	0	-		
97-99	0	0	-		
100-102	2	0	-		
TOTALS	164	390			
	102 $\Sigma A = 122$ 49	102 $\Sigma B = 348$ 49	$\frac{B}{A} = 2.85$		

Figure


SELECTION CURVES – POLLOCK
%
% RETENTION
100
80
60
50
40
20
0
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 128 134 CM
10 15 20 25 30 35 40 45 50 IN
LENGTH
138 MM COVERED
138 MM UNCOVERED

Figure


CATCH DISTRIBUTION – POLLOCK
% OF TOTAL CATCH
30
25
20
15
10
5
0
26 32 38 44 50 56 62 68 74 80 86 92 98 104 110 116 122 CM
10 15 20 25 30 35 40 45 IN
LENGTH
COD ENDS + COVERS
107 MM COD ENDS
138 MM COD ENDS

55

Winter flounder

The results in this section are based on data from Experiments One, Two, and Four, representing a total catch of 4,152 winter flounder.

There were insufficient data to calculate the selection factors from the uncovered tows in Experiment One and from both covered and uncovered tows in Experiment Four. However, with all data combined, fairly good results were obtained (Tables to , Figure). There again is an increase in selection factor with the larger mesh. An overall selection factor of 2.2 for winter flounder seems a reasonable choice based on this data. The 25-75% selection range was in most cases about 5 cm.

From the uncovered-tow data (Table) there seems to be an increase in efficiency for the larger mesh starting at about the 34-36-cm fish length interval. Choosing a discard (cull) point of 30 cm, it can be seen that the large mesh landed more fish by numbers and weight (Table). The large mesh, using the 30-cm cull point, decreased discards by 73% by weight.

Table . Winter flounder selection factor summary.

Experiment	Total no. of fish	Selection factor		
		Sm mesh	Lg mesh	Alternate tow
One	725	2.07	2.23	-
Two	2,398	2.02	2.05	2.21
Four	1,029	-	-	-
Combined	4,152	2.04	2.07	2.27

Table . Winter flounder length frequency distributions and percent retained for the small-mesh (103-mm overall average) covered tows--six vessels.

Length interval (cm)	Numbers caught		% retained
	103 mm	103 mm plus covers	
10-12	0	0	0.0
13-15	1	9	11.1
16-18	3	11	27.3
19-21	10	30	33.3
22-24	96	109	88.1
25-27	161	170	94.7
28-30	204	209	97.6
31-33	161	164	98.2
34-36	83	84	98.8
37-39	68	68	100.0
40-42	70	70	100.0
43-45	46	46	100.0
46-48	24	24	100.0
49-51	15	15	100.0
52-54	2	2	100.0
55-57	2	2	100.0
58-60	1	1	100.0
TOTALS	947	1,014	

Table . Winter flounder length frequency distributions and percent retained for the large-mesh (133-mm overall average) covered tows--six vessels.

Length interval (cm)	Numbers caught		% retained
	133 mm	133 mm plus covers	
10-12	0	0	0.0
13-15	0	6	0.0
16-18	1	45	2.2
19-21	9	107	8.4
22-24	17	120	14.2
25-27	58	158	36.7
28-30	145	241	60.2
31-33	127	155	81.9
34-36	86	92	93.5
37-39	54	56	96.4
40-42	58	59	98.3
43-45	51	51	100.0
46-48	19	19	100.0
49-51	16	16	100.0
52-54	11	11	100.0
55-57	6	6	100.0
58-60	3	3	100.0
61-63	1	1	100.0
TOTALS	662	1,146	

Table . Winter flounder length frequency distributions and percent retained from uncovered cod end tows--six vessels.

Length interval (cm)	Numbers caught (A) 103 mm	Numbers caught (B) 133 mm	$\frac{B}{A}$		% retained by 133 mm $\frac{B}{1.2A} \times 100$
10-12	0	0	0.00		0.0
13-15	0	0	0.00		0.0
16-18	0	0	0.00		0.0
19-21	16	0	0.00		0.0
22-24	115	10	0.08		7.2
25-27	204	30	0.15		12.3
28-30	265	99	0.37		31.1
31-33	168	148	0.88		73.4
34-36	90	185	2.06		171.3
37-39	85	106	1.25		103.9
40-42	103	113	1.10	Avg.	91.4
43-45	62	65	1.05	1.2	87.4
46-48	32	43	1.34		110.1
49-51	8	16	2.00		166.7
52-54	6	13	2.17		180.6
55-57	3	6	2.00		166.7
58-60	1	0	0.00		0.0
TOTALS	1,158	834			

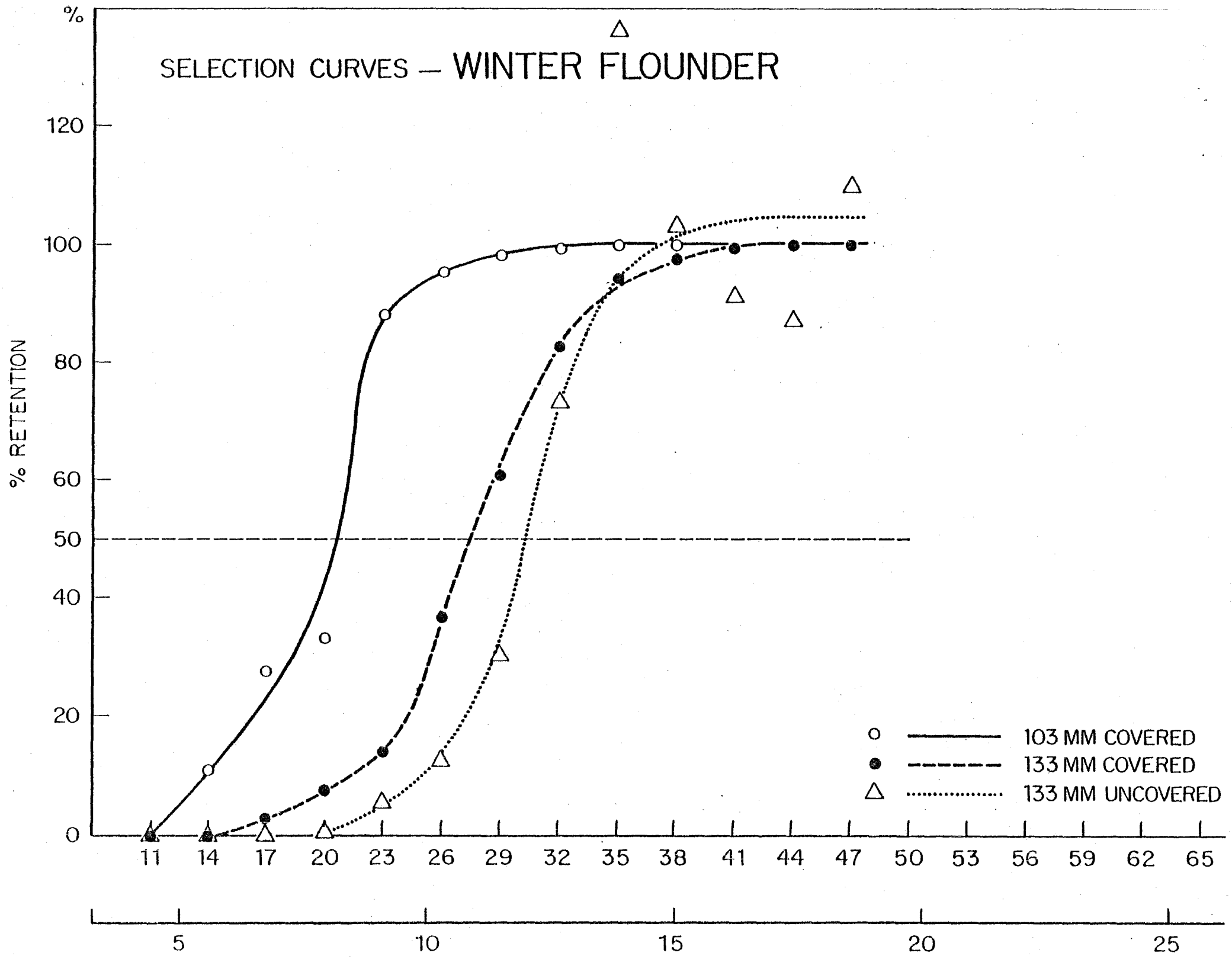

SELECTION CURVES — WINTER FLOUNDER
%
120
100
80
60
50
40
20
0
% RETENTION
11
14
17
20
23
26
29
32
35
38
41
44
47
50
53
56
59
62
65
5
10
15
20
25
103 MM COVERED
133 MM COVERED
133 MM UNCOVERED

Table . Winter flounder length frequency distributions.

Length interval (cm)	Cod ends plus covers			Cod ends only Uncovered tows		Industry
	Overall average	103 mm	133 mm	103 mm	133 mm	
10-12	0.0	0.0	0.0	0.0	0.0	
13-15	0.7	0.9	0.5	0.1	0.0	
16-18	2.5	1.1	3.9	0.3	0.2	
19-21	6.2	3.0	9.3	1.1	1.4	
22-24	10.6	10.7	10.5	10.1	2.6	
25-27	15.3	16.8	13.8	17.0	8.8	
28-30	20.8	20.6	21.0	21.5	21.9	
31-33	14.9	16.2	13.5	17.0	19.2	
34-36	8.2	8.3	8.0	8.8	13.0	
37-39	5.8	6.7	4.9	7.2	8.2	
40-42	6.0	6.9	5.1	7.4	8.8	
43-45	4.5	4.5	4.5	4.9	7.7	
46-48	2.1	2.4	1.7	2.5	2.9	
49-51	1.5	1.5	1.4	1.6	2.4	
52-54	0.6	0.2	1.0	0.2	1.7	
55-57	0.4	0.2	0.5	0.2	0.9	
58-60	0.2	0.1	0.3	0.1	0.5	
61-63	0.05		0.1	21.0	0.2	
TOTALS		1,014	1,146	947	662	

Table . Winter flounder landings.

Length interval (cm)	kg/fish	Small uncovered		Large uncovered	
		no.	kg	no.	kg
10-12	0.05	0	0.0	0	0.0
13-15	0.07	0	0.0	0	0.0
16-18	0.09	0	0.0	0	0.0
19-21	0.11	16	1.8	0	0.0
22-24	0.18	115	20.7	10	1.8
25-27	0.23	204	46.9	30	6.9
28-30	0.36	265	95.4	99	35.6
31-33	0.45	168	75.6	148	66.6
34-36	0.55	90	49.5	185	101.8
37-39	0.77	85	65.5	106	81.6
40-42	0.91	103	93.7	113	102.8
43-45	1.14	62	70.7	65	74.1
46-48	1.36	32	43.5	43	58.5
49-51	1.68	8	13.4	16	26.9
52-54	2.05	6	12.3	13	26.7
55-57	2.43	3	7.3	6	14.6
58-60	2.93	1	2.9	0	0.0
61-63	3.42	0	0.0	0	0.0
TOTALS		1,158	599.2	834	597.9
Landings (discard ≤30 cm)		558	434.4	695	553.6
Discard		600	165.0	139	44.3
% discard		51.8%	27.5%	16.6%	7.4%

% reduction in discard between mesh sizes: 73% by weight.

American plaice

The results in this section represent the data from 32 tows made during Experiment Two. The total catch consisted of 3,798 American plaice.

A visual inspection of Table and Figure shows the length-frequency distribution between the two vessels to be about the same. Some masking is evident in the large covered cod ends, but with the large number of small fish caught this was probably unavoidable.

Selection data for the 99-mm covered cod-end tows are given in Table and the corresponding selection curve is shown in Figure . The 50% retention length of approximately 23.3 cm (9.2 inches) gives a selection factor of 2.35. The 25-75% selection range is approximately 3.6 cm (1.4 inches).

Selection data for the 131-mm covered cod-end tows are given in Table and Figure . The 50% retention length of approximately 29.5 cm (11.6 inches) gives a selection factor of 2.25. The 25-75% selection range is approximately 6 cm (2.4 inches).

Selection data for the 99-mm and 131-mm uncovered tows are given in Table and Figure . There was near equal retention above the 100% retention point, thus the distributions were considered equivalent. From this method, a 50% retention length of 31.6 cm (12.4 inches) is obtained for the 131-mm cod end which gives a selection factor of 2.41. The 25-75% selection range is approximately 7 cm (2.8 inches).

From this data a choice of 2.3 for the American plaice selection factor seems reasonable and is in agreement with past studies (Holden 1971).

Figure is the catch distribution of the two cod-end sizes compared to the overall available population. Table does not indicate anything in regard to efficiency but does show discards can be reduced by 50% using the larger mesh.

Table . Length frequency distributions (%)--American plaice (dabs).

Length interval (cm)	Cod ends and covers					Cod ends only			
	Overall average	99 mm	131 mm	LINDA B	METACOMET	99 mm covered	99 mm uncovered	131 mm covered	131 mm uncovered
10-12	1.2	1.0	1.3	0.6	1.8	0.2	0.0	0.0	0.0
13-15	19.4	10.8	23.8	17.8	21.2	2.9	0.8	5.5	0.5
16-18	26.4	24.2	27.5	25.0	28.0	5.3	2.3	5.5	0.5
19-21	17.9	19.6	17.1	18.5	17.2	6.2	5.4	6.3	1.8
22-24	13.4	14.5	12.9	14.6	12.1	13.9	15.3	11.1	2.8
25-27	7.6	9.6	6.6	7.7	7.4	20.8	22.5	11.8	11.0
28-30	4.6	6.4	3.7	5.1	4.0	16.0	16.3	12.5	12.8
31-33	2.2	3.5	1.5	2.6	1.8	8.6	9.1	6.9	10.6
34-36	1.4	2.3	0.9	1.6	1.2	5.7	7.2	6.6	18.3
37-39	1.6	1.9	1.4	1.6	1.6	4.8	5.2	10.1	8.7
40-42	0.9	1.5	0.6	0.9	0.9	3.8	2.5	4.2	6.9
43-45	1.0	1.1	0.9	1.0	1.0	2.9	5.6	6.6	7.8
46-48	1.0	1.5	0.7	1.2	0.8	3.8	3.1	4.9	7.8
49-51	0.7	1.1	0.4	0.9	0.5	2.6	2.1	3.1	4.1
52-54	0.5	0.6	0.4	0.6	0.3	1.4	1.9	2.8	4.1
55-57	0.2	0.3	0.2	0.2	0.3	0.7	0.4	1.4	1.8
58-60	0.1	0.1	0.1	0.2	0.0	0.2	0.2	0.7	0.0
61-63							0.2		0.0
64-66									0.5
TOTALS	3,096	1,051	2,045	1,639	1,457	418	484	288	218

Figure

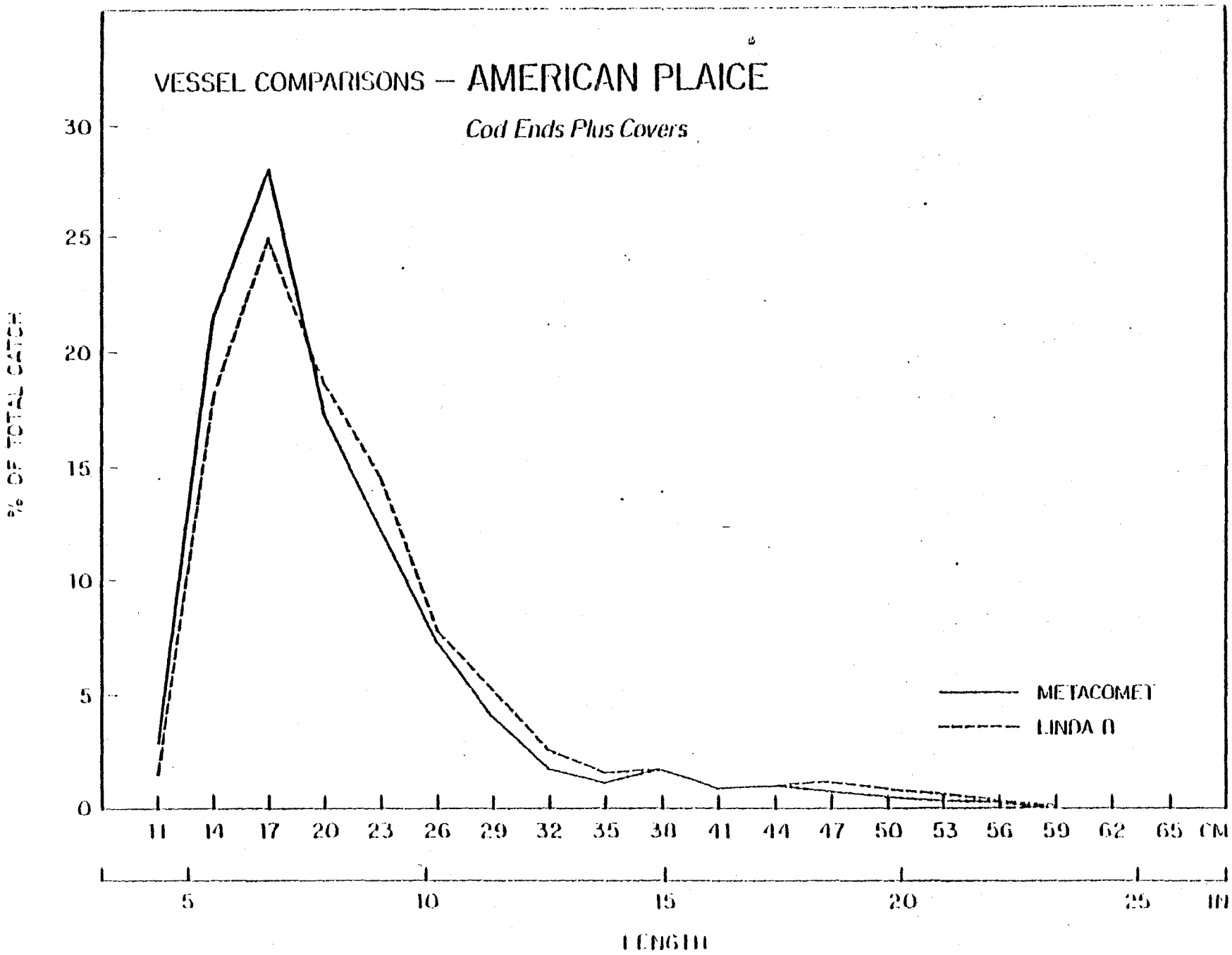

VESSEL COMPARISONS – AMERICAN PLAICE
Cod Ends Plus Covers
% OF TOTAL CATCH
30
25
20
15
10
5
0
METACOMET
LINDA D
11 14 17 20 23 26 29 32 35 38 41 44 47 50 53 56 59 62 65 CM
5 10 15 20 25 IN
LENGTH

Table . American plaice length frequency distributions and percent retained for 99-mm cod end covered tows--LINDA B and METACOMET.

Length interval (cm)	Numbers caught		% retained
	99 mm	99 mm plus covers	
10-12	1	10	10.0
13-15	12	114	10.5
16-18	22	254	8.7
19-21	26	206	12.6
22-24	58	152	38.2
25-27	87	101	86.1
28-30	67	67	100.0
31-33	36	37	97.3
34-36	24	24	100.0
37-39	20	20	100.0
40-42	16	16	100.0
43-45	12	12	100.0
46-48	16	16	100.0
49-51	11	12	91.7
52-54	6	6	100.0
55-57	3	3	100.0
58-60	1	1	100.0
TOTALS	418	1,051	

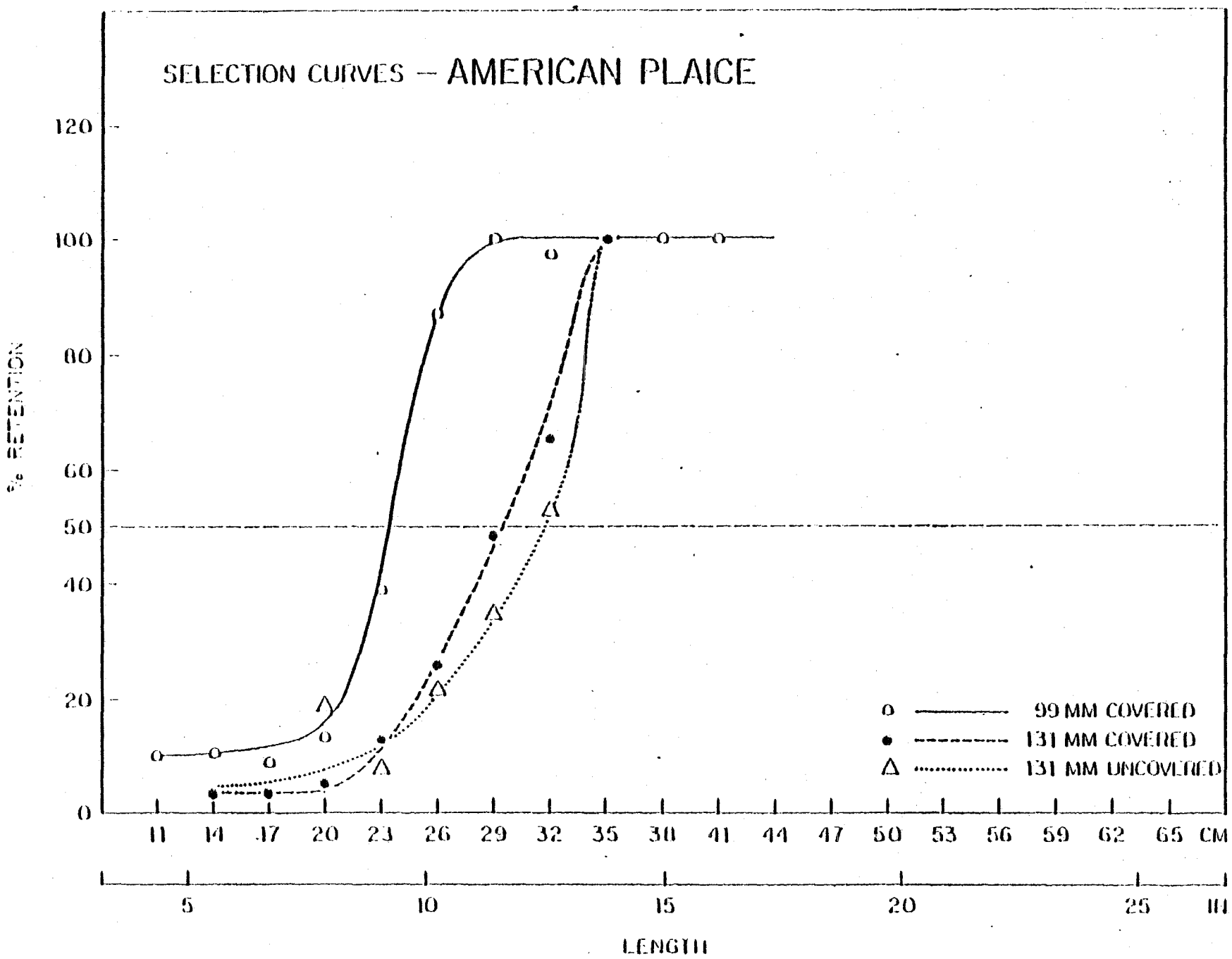
Table . American plaice length frequency distributions and percent retained for 131-mm cod end covered tows--LINDA B and METACOMET.

Length interval (cm)	Numbers caught		% retained
	131 mm	131 mm plus covers	
10-12	0	27	0.0
13-15	16	487	3.3
16-18	16	563	2.8
19-21	18	349	5.2
22-24	32	263	12.2
25-27	34	134	25.4
28-30	36	75	48.0
31-33	20	31	64.5
34-36	19	19	100.0
37-39	29	29	100.0
40-42	12	12	100.0
43-45	19	19	100.0
46-48	14	14	100.0
49-51	9	9	100.0
52-54	8	8	100.0
55-57	4	4	100.0
58-60	2	2	100.0
TOTALS	288	2,045	

Table . American plaice length frequency distributions and percent retained for the 131-mm uncovered cod end compared with the 99-mm uncovered cod end--LINDA B and METACOMET.

Length interval (cm)	Numbers caught (A) 99 mm	(B) 131 mm	$\frac{B}{A} \times 100 =$ % retained by 131 mm
10-12	0	0	0.0
13-15	4	1	25.0
16-18	11	1	9.1
19-21	26	4	16.7
22-24	74	6	8.1
25-27	109	24	22.0
28-30	79	28	35.4
31-33	44	23	52.3
34-36	35	40	114.3
37-39	25	19	76.0
40-42	12	15	125.0
43-45	27	17	63.0
46-48	15	17	113.3
49-51	10	9	90.0
52-54	9	9	100.0
55-57	2	4	200.0
58-60	1	0	-
61-63	1	0	-
64-66	0	1	-
TOTALS	484	218	
	66 ΣA=137 34	66 ΣB=131 34	

Figure


SELECTION CURVES – AMERICAN PLAICE
% RETENTION
120
100
80
60
50
40
20
0
11 14 17 20 23 26 29 32 35 38 41 44 47 50 53 56 59 62 65 CM
5 10 15 20 25 30
LENGTH
99 MM COVERED
131 MM COVERED
131 MM UNCOVERED

Figure

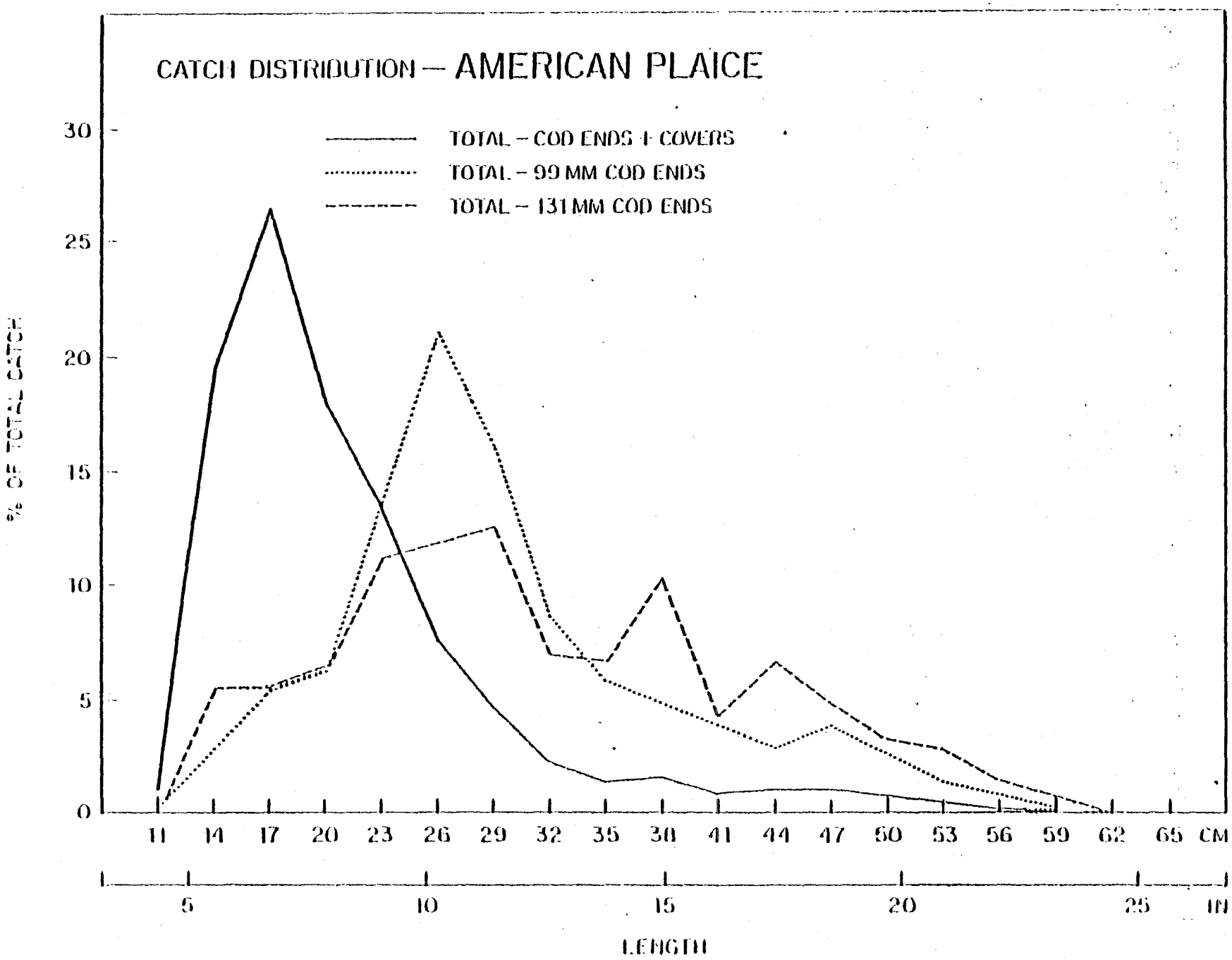

CATCH DISTRIBUTION — AMERICAN PLAICE
TOTAL – COD ENDS + COVERS
TOTAL – 99 MM COD ENDS
TOTAL – 131 MM COD ENDS
% OF TOTAL CATCH
30
25
20
15
10
5
0
11 14 17 20 23 26 29 32 35 38 41 44 47 50 53 56 59 62 65 CM
5 10 15 20 25 IN
LENGTH

Table . American plaice landed weight and discard summary--LINDA B and METACOMET, with an assumed discard at 30 cm (11.8 inches).

	Small cod ends		Large cod ends	
	Weight (kg)	% discards	Weight (kg)	% discards
Day 1:	28.4	29.4	32.7	15.6
Day 2:	149.4	25.1	44.2	15.6
Day 3:	12.0	41.2	7.5	20.2
Day 4:	34.8	30.0	133.7	11.4
Overall discard average:		31.4		15.7

Reduction in discards: 50.0%

Catch summary by *numbers* of fish

No. discarded:	Small uncovered - 303	Large uncovered - 64
No. landed:	- 181	- 154
TOTAL:	- 484	- 218
% discard:	- 62.6	- 29.4

Discards

In New England the term "discard" can mean anything in the catch that is thrown back overboard. This can include desirable species too small to market, unmarketable species, and bottom trash such as rocks. A marketable fish can become discard by management decisions such as quotas or size limits. The captain also makes the economic decision of retaining certain species and sizes based on price and markets available.

Probably ever since commercial fishing with nets began, fishermen have been discarding fish too small to market and hook-and-line fishermen have been complaining about it. In England in 1558 these complaints caused Queen Elizabeth I to issue a royal decree setting a minimum mesh size of 2½ inches (Jensen 1972).

In New England the complaints reached a crescendo soon after the introduction of the otter trawl--an introduction made by Captain Collins, Chairman of the U. S. Fish Commission, in 1903. By 1912 the first American steam trawler, Spray, and five sister ships, Foam, Ripple, Crest, Surf, and Swell, were routinely fishing Georges Bank. To address the complaints, David Belding, a biologist for the Massachusetts Commission on Fisheries and Game, conducted an investigation on the effects of otter trawling by making a trip on the F/V Foam in that year (Belding 1916).

During Belding's trip the vessel discarded as undersized about 25% of the haddock and 14% of the cod caught. He assumed 100% mortality for these discarded fish. The cod-end mesh size was probably smaller than 3 inches.

Belding's work was soon followed by that of Alexander, Moore, and Kendall (1915) as described in the introduction of this report. From data collected on 61 trips, they found that by weight ". . . 40 percent of the cod and 38 percent of the haddock taken by the otter trawlers from June to December were

fish too small to market. From January to May but 3 percent of the cod and 11 percent of the haddock were unmarketable on account of their size." By numbers, for haddock, this amounted to 77 and 40%, respectively (Herrington 1935). Their observers reported practically all of these discarded fish as dead when thrown over the side. The cod-end mesh size was about 2½ inches.

Herrington's work in the 1930-31 period, when small haddock were unusually abundant, indicated discards of undersized fish two to three times larger than marketable haddock (Herrington 1932). He goes on to say that the commercial captains were concerned enough about this to make an agreement among themselves to avoid grounds where small fish predominated. However, the small fish were everywhere, making the agreement ineffective. In that one-year period, 1930-31, about 63,000,000 baby haddock were destroyed, ". . . about equal to the number of haddock in a commercial catch of 200,000,000 pounds" (Herrington 1936). Again, this destruction varied by season, area fished, and yearly.

Premetz (1953) reported that for the 1947-51 period annual discards of undersized haddock were over 4½ million pounds, representing over 6% of the catch. The greatest part of the destruction occurred from June to November. His data further show that the overlap in culling between discards and fish retained for market ranged from 11 to 19 inches (0.5 to 2.3 lb) and was usually a function of the size of the catches. The majority of the culling occurred between 13 and 15 inches (33 and 38 cm).

From fishermen's reports, the discard of 1975 year-class haddock during 1977 was very high. It may have been of the same order of magnitude as that reported for the 1930-31 period mentioned above. Even though there was a mesh-size regulation in effect, reports indicate that many fishermen geared down, either using a smaller mesh or liner, to catch the abundant scrod haddock.

Haddock and cod are not the only fish discarded. Lux (1968) reported yellowtail flounder discards of 50% of the catch by weight. This was using mesh sizes of about 114 mm and a cull point of about 35 cm. The survival of discarded yellowtail was estimated by Lux to be about 25%. The average discards and landings for 1963-66 averaged about 11,000 and 33,000 metric tons, respectively (Hennemuth and Lux 1970).

Table summarizes the results, in regard to discards, of the catches made during this series of experiments as reported in the previous sections of this paper. For cod, haddock, and winter flounder, there was a reduction of discards and an increase in landings by the larger mesh. For yellowtail flounder there was a reduction of discards and of landings.

In reviewing this data, the question arises that if this overall increase in catch and decrease in discards is in fact true, why haven't the fishermen optimized their operation by going to a larger mesh (5 inches or greater)? Several hypotheses are offered, as follows:

1. Evolutionary development (gear). The otter trawl has only been fished in New England for 75 years. During this period there has been an increase in mesh size and many "highliner" captains do use mesh sizes over 5 inches. Evolutionary development is a long process and just may not be complete in regard to optimizing mesh size.

2. Economics. The catch of smaller species of fish, i.e., whiting, may offset the loss of catch of larger groundfish caused by reduced trawl efficiency. The inshore fleet may be a good example of this.

3. Natural cycle variations. Every so often a good year class of cod or haddock comes along. The fishermen will fish these schools when only a small portion of the fish have reached market size and thus will use a mesh size

that would retain 100% of the scrod, roughly a 4-inch mesh. Anyone using a larger mesh will most likely catch fewer marketable fish.

4. Observation. It is harder to see catch-efficiency improvements when compared to seeing marketable fish escaping through the meshes when the net is at the surface.

Table . Discard summary for New England mesh experiments using only uncovered cod-end data.

	Small cod ends		Large cod ends	
	No.	kg	No.	kg
Species:	COD			
Mesh sizes:	105 mm (4.1 inches)		135 mm (5.3 inches)	
Total catch:	1,148	2,537.4	1,016	3,203.7
Landings (discard ≤42 cm):	823	2,362.6	983	3,184.6
Discard (≤42 cm):	325	174.8	33	19.1
% discard:	28.3%	6.9%	3.2%	0.6%
	Larger mesh reduced discards 93% by weight. Larger mesh increased landings 35% by weight.			
Landings (discard <52 cm):	605	2,145.0	898	3,095.1
Discard (<52 cm):	543	392.4	118	108.6
% discard:	47.3%	15.5%	11.6%	3.4%
	Larger mesh reduced discards 78% by weight. Larger mesh increased landings 44% by weight.			
Species:	HADDOCK			
Mesh sizes:	107 mm (4.2 inches)		138 mm (5.4 inches)	
Total catch:	1,372	2,271.5	1,544	2,784.8
Landings (discard ≤42 cm):	1,310	2,229.1	1,534	2,777.6
Discard (≤42 cm):	62	42.4	10	7.2
% discard:	4.5%	1.9%	0.6%	0.3%
	Larger mesh reduced discards 84% by weight. Larger mesh increased landings 25% by weight.			
Landings (discard <52 cm):	967	1,829.9	1,307	2,495.2
Discard (<52 cm):	405	441.6	237	289.6
% discard:	29.5%	19.4%	15.3%	10.4%
	Larger mesh reduced discards 46% by weight. Larger mesh increased landings 36% by weight.			

Table . Discard summary (cont.)

	Small cod ends		Large cod ends	
	No.	kg	No.	kg
Species:	YELLOWTAIL FLOUNDER			
Mesh sizes:	102 mm (4.0 inches)		133 mm (5.2 inches)	
Total catch:	3,842	1,416.7	1,909	944.0
Landings (discard ≤30 cm):	2,424	1,223.6	1.714	911.9
Discard (≤30 cm):	1,418	193.1	195	32.1
% discard:	36.9%	13.6%	10.2%	3.4%
	Larger mesh reduced discards 75% by weight. Larger mesh reduced landings 25% by weight.			
Landings (discard ≤36 cm):	1,024	706.3	862	592.7
Discard (≤36 cm):	2,818	710.4	1,047	351.3
% discard:	73.3%	50.1%	54.8%	37.2%
	Larger mesh reduced discards 26% by weight. Larger mesh reduced landings 16% by weight.			
Species:	WINTER FLOUNDER			
Mesh sizes:	103 mm (4.1 inches)		133 mm (5.2 inches)	
Total catch:	1,158	599.2	834	597.9
Landings (discard ≤30 cm):	558	434.4	695	553.6
Discard (≤30 cm):	600	165.0	139	44.3
% discard:	51.8%	27.5%	16.6%	7.4%
	Larger mesh reduced discards 73% by weight. Larger mesh increased landings 27% by weight.			
Landings (discard ≤36 cm):	300	309.1	362	385.2
Discard (≤36 cm):	858	290.1	472	212.7
% discard:	74.1%	48.4%	56.6%	35.6%
	Larger mesh reduced discards 26% by weight. Larger mesh increased landings 25% by weight.			

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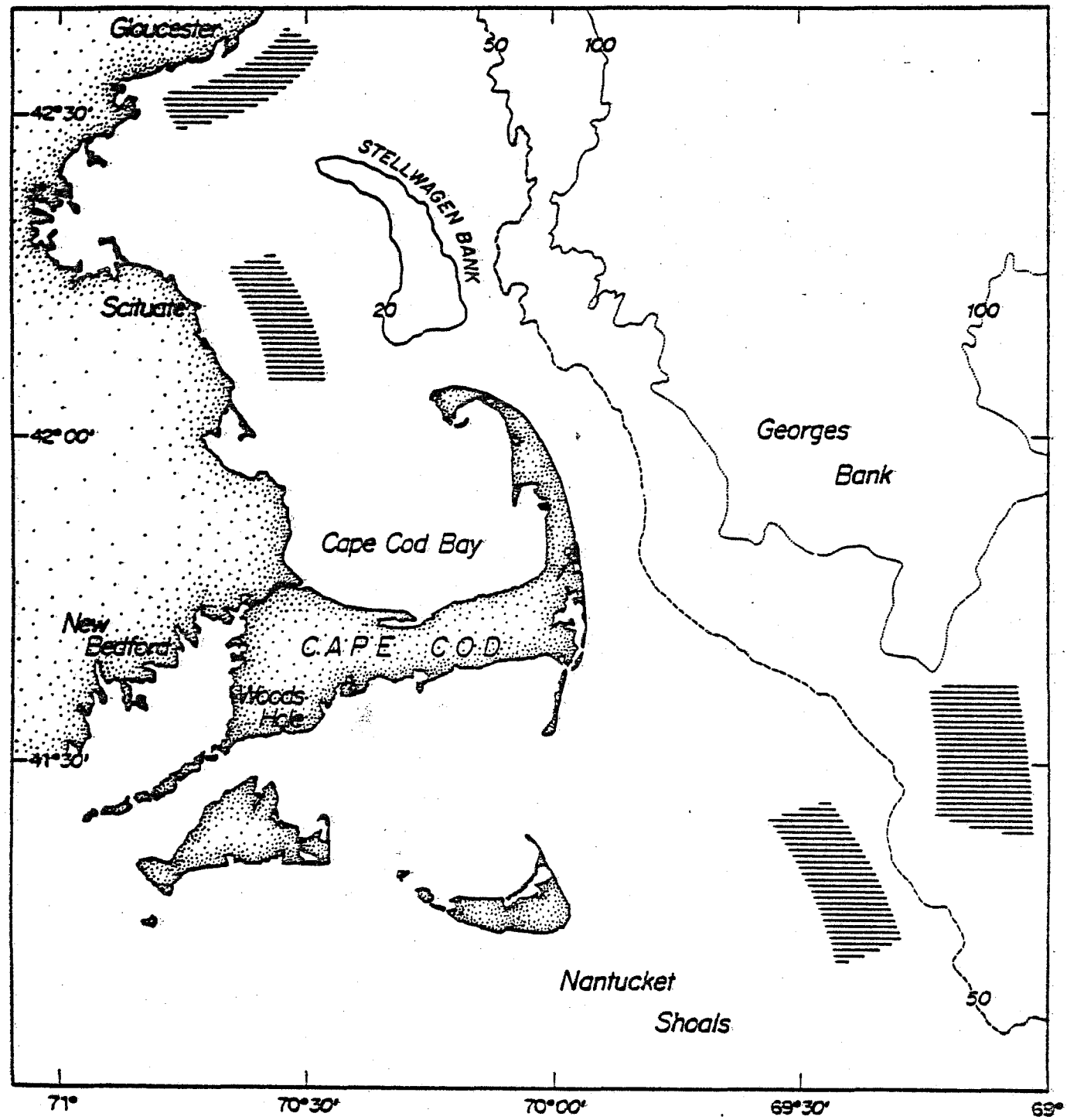
Gloucester
30
100
42°30'
STELLWAGEN BANK
Scituate
20
100
42°00'
Georges
Bank
Cape Cod Bay
New
Bedford
CAPE COD
Woods
Hole
41°30'
Nantucket
Shoals
50
71°
70°30'
70°00'
69°30'
69°