

Analysis of Size Selectivity and Bycatch in the Gillnet Fishery for Monkfish



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ABSTRACT

Goosefish, commonly referred to as monkfish, is a commercially important finfish species in New England that is mainly targeted by otter trawl and large-mesh gillnets (10" or greater). Despite the commercial importance of this species, there is limited information regarding the size selection of monkfish between these gear types and between gillnet mesh sizes, particularly in the Gulf of Maine. There is also limited information describing bycatch composition and rates between gillnet mesh sizes. In this study monkfish were targeted using an otter trawl and tiedown gillnets with either a 10", 12", and 14" mesh size. We used the F/V Kirsten Lee during this study, a commercial monkfish vessel that can deploy both trawl and gillnet fishing gear during the same fishing trip. This study occurred in the Gulf of Maine during the summer fishery for monkfish. For the gillnet gears, we found the 12" mesh gillnet had the highest catch of monkfish by weight and the 14" gillnet had the lowest catch both by weight and number. The catch from the 12" and 14" gillnets was dominated by female monkfish. Individual monkfish length increased with an increase in gillnet mesh size, and the length of trawl-caught monkfish was significantly smaller than that for gillnet-caught fish. Also noted was a significant difference in the length / girth ratio for monkfish between the trawl and gillnet caught fish. Bycatch levels were highest in the 10" gillnets while the lowest levels were seen in the 12" gillnets. The major bycatch species included spiny dogfish, American lobster, thorny skate and Atlantic cod. A decrease in bycatch of spiny dogfish, American lobster and Atlantic cod was noted as the mesh size increased while the thorny skate bycatch increased with mesh size.

INTRODUCTION

Goosefish (*Lophius americanus*) are distributed along the eastern coast of North America from the Grand Banks and the northern side of the Gulf of Saint Lawrence southward to North Carolina (Collette and Klein-MacPhee 2002). They are a demersal species that can be found from inshore areas to depths of at least 500 fathoms (Collette and Klein-MacPhee 2002). Goosefish are more commonly referred to by their market name, monkfish (FDA 1988).

A monkfish fishery occurs along the northeast coast from Maine to North Carolina. This fishery developed in the early 1990's as growth in demand and value of the resource increased significantly (Haring and Maguire 2008). Monkfish are harvested commercially primarily by three gear types: trawl, gillnet and scallop dredge (NEFSC 2007a). The management area for this species is divided into two sub areas (Figure 1): Northern Fishery Management Area (NMA) and the Southern Fishery Management Area (SMA) (NEMFC 1998). This division is based on differences in how the fishery is prosecuted in the two regions (Haring and Maguire 2008).

Monkfish landings from the NMA come primarily from the trawl fishery. In 2006, trawls accounted for 74% of the total landings from this region, however, there has been a shift in landings to the other two gear types over time (NEFSC 2007a). Prior to 1994, gillnet catches contributed ~7% to the total landings while scallops dredge gear accounted for ~21%. Since then, gillnet landings have increased dramatically while the scallop dredge landings have been on the decline. In 2006, gillnets and scallop dredges accounted for 22.1% and 0.5% respectively of the catch of monkfish from this region.

Of the three primary gears used to catch monkfish along the coast, gillnets with a minimum mesh size of 10" appear to have the lowest bycatch rate by weight (6.9%) and the trawl fishery the highest (32.3%) based on 2001-2002 observer data (NEFMC 2004). Prominent bycatch species in the large mesh gillnet fishery were skates (winter and thorny) and spiny dogfish (NEFMC 2004). American lobster, Atlantic cod and jonah crab were also a minor part of the bycatch in this fishery (NEFMC 2004).

Based on observer and vessel trip reporting from 1996 – 2006, the gillnet fishery had the lowest level of monkfish discards (NEFSC 2007a). Monkfish were discarded predominantly for quality reasons in the gillnet fishery and size (for both market and regulatory reasons) in the trawl fishery. Size was cited as a minor reason for discard in the gillnet fishery. Between 2001 and 2002, monkfish discards in the trawl fishery were 12.0% of the total catch with 74.8% resulting from undersized monkfish. In comparison, the gillnet fishery monkfish discards were 1.9% of the total catch, but only 2.3% of these were "too small" (NEFMC 2004).

Recent work has examined monkfish size selection in trawl gear. The Manomet Center for Conservation Science (MCCS) (2004) conducted a pilot project to collect data on the efficiency of a 10" mesh codend built specifically to target monkfish. GMRI and MCCS (2005) tested both a trawl net with 12" mesh throughout and a trawl net with a 6" mesh in

the body and a 12"codend to assess bycatch rates and monkfish size selectivity. Gillnet gear size selectivity for monkfish has been lacking (NEFMC 1998). The most recent stock assessment for monkfish (NEFSC 2007a) included gillnet gear size selectivity as one of the research recommendations, i.e. "*... comparative studies of the size selectivity and catchability of trawls and gillnets should be undertaken in order to understand the differences in the numbers of large fish captured in the two gear types.*"

OBJECTIVES

The goal of this project is to directly address the research recommendation from the Monkfish Fishery Management Plan and the research priorities from the Monkfish Assessment Report for 2007 and to provide information that can be used to develop a cleaner monkfish fishery.

The project's objectives are threefold:

- 1) Collect data on bycatch rates for species captured in monkfish gillnets ranging from 10" to 18" mesh size.

The hypothesis is that larger mesh gillnets will maintain monkfish catches, while reducing the catch of non-target species such as cod. Our intent is to demonstrate the impact of larger mesh sizes on bycatch rates in the directed monkfish gillnet fishery and any additional important implications for managing the fishery while assessing the reduction of the bycatch of cod and other species through mesh size.

- 2) Compare size composition of monkfish catches from trawls and gillnets.

The industry indicates that gillnets tend to catch larger monkfish than trawls. Conducting both gillnet sets and trawls in the same area and time will provide evidence either supporting or refuting this notion.

- 3) Establish size selectivity curves for monkfish using 10", 12", 14", 16" and 18" gillnets.

The project partners predict gillnets of different mesh sizes will demonstrate different size selectivity curves and that as the mesh size is increased, the average size of retained monkfish will increase.

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METHODS

Research was conducted aboard the F/V Kirsten Lee (O.N. 680488), a 50' (LOA) vessel equipped to fish with both otter trawl and gillnets (Figure 2). Sampling was conducted in the coastal waters of the Gulf of Maine between Boon Island and Cape Porpoise, ME, generally between 30 and 65 fathoms depth (Figure 3). This area was chosen by previous success in capturing monkfish at this time of year. Decisions on daily adjustments of gear location were based on haul performance and the local area knowledge of the captain, Stephen Lee.

The trawl net used was a low rise net constructed by Stephen Lee to target monkfish and flatfish. The net had a one legged bridle and a 137 foot sweep made up of 60 foot wings and a 17 foot bosom. Roller gear included 8 inch rubber disks (cookies) in the bosom, extending to 6 inch cookies on the first 10 feet of the wings, and 5.5 inch cookies on the remainder of the wings. The ground cables were 20 fathoms in length and covered with 4 inch cookies. The body of the net was composed of 6 inch green polyethylene diamond mesh with a fishing circle of 342 meshes. The codend was 6.5 inch knotted green

polyethylene material hung on the square with double mesh. The net was towed with Bison #7 doors at an average speed of 2.5 knots.

The original proposal called for the comparison of five separate gillnet mesh sizes (10", 12", 14", 16" and 18") to determine size selectivity. However, due to difficulty in locating and ordering the net webbing, the 16" and 18" mesh gillnets were not used. Although a manufacturer was eventually found to produce the gear, the stated cost for the small amount of netting required was prohibitive. Since these mesh sizes were well above that which is commonly used by the industry, it was decided (and approved by the funding agency) that using 10", 12" and 14" mesh gillnets only would still yield results relevant to the fishery. Because the 16" and 18" mesh size gillnets were omitted from the study, the total number of experimental nets per mesh size was increased from 10 to 12.

Gillnets were ordered from IMP Marine (New Bedford, Massachusetts). Individual nets were constructed according to the specifications found in Table 1. Upon delivery of the

Table 1. Nominal gillnet gear specifications.

Net characteristic	Specification
Net length	300' each
Net height	8'
Mesh size (vertical mesh count)	10" (14), 12" (12), 14" (10)
Hanging ratio	1 / 2
Twine size	30 (0.90 mm)
Twine color	green
Distance between floats	12.5'
Tiedown height	42"
Distance between tiedowns	25'
Leadline weight	43 lbs / net
1100 lbs break away links	5 per net

nets, four gillnet strings were assembled. All strings contained nine gillnets with 3 nets of each mesh size (Table 2). A five fathom bridle was placed in between each individual net in order to prevent the mesh size of a net from influencing the catch of each neighboring net.

Table 2. Gillnet string configurations.

Gillnet String #	Gillnet String Configuration
1 and 3	10"-12"-14"-12"-14"-10"-14"-10"-12"
2 and 4	14"-12"-10"-12"-10"-14"-10"-14"-12"

Trawls were conducted immediately before gillnet retrievals, in a location of similar depth strata close to the gillnet gear and located to not drive fish either into or away from the gillnets. Midway through the sampling schedule, the number of gillnet strings set and hauled per day was increased from 2 to 4 to increase the sample size of monkfish per gillnet mesh size. This did not change fishing methodology as all nets still soaked for ~48 hrs.

Catch was separated by gear type, mesh size and species upon haul back. All monkfish were measured for weight to the nearest tenth of a kilogram and length and girth to the nearest centimeter. Girth was recorded from the widest region of the head just before the pectoral fins (Figure 4) using a customized length board with a slide and attached line that could wrap around the fish with light hand pressure applied. Sex of monkfish (Figure 5) was recorded for all individuals that were processed for commercial sale. Total weights and individual lengths were recorded for other species.

Maximum likelihood was used to calculate and fit monkfish selection curves with the SELECT method (Millar and Holst 1997), which uses the proportion of the total catch taken by each net. To determine if adjustment for fishing effort was necessary, a subsample of gillnets (3 per mesh size) were measured for length, overall height and tiedown height. Four unimodal (normal scale, normal location, lognormal and gamma) and one bimodal curve (a mixture of two normal curves) were fit to individual gillnet hauls with >10 individuals caught and to the lengths pooled over all catches, using proprietary software (GillNet, www.constat.dk). Curves were judged by their relative goodness-of-fit (GOF: model deviance divided by degrees of freedom) and frequency of convergence.

Residual maximum likelihood (REML) was used next to estimate a mean selection curve from the curves fit to individual hauls, incorporating between-haul variation. The REML method was implemented with software (ECWEB, www.constat.dk) based on work by Fryer (1991) that allows fitting of the same five types of curves to the combined individual curves. The fit of the resulting mean curves was evaluated using Akaike's Information Criteria (AIC).

DATA

Data collected for this project included gillnet and trawl gear characteristics, location and timing of the sets and the associated catch (Table 3) as well as biological and environmental data for all hauls conducted. A Microsoft Office Access Database was created for data management and will be submitted for inclusion into the Northeast Consortium Fisheries & Ocean Database.

RESULTS

Sampling with both gears was conducted every other day from July 1 through July 29, 2008 for a total of 15 days (Table 3). The trawl net was deployed 29 times with a tow duration of 20 minutes. Gillnets strings 1 and 2 were each set and hauled 11 times and strings 3 and 4 were each set and hauled 10 times. All gillnets were set for a 2 night soak (~48 hours). With 3 nets of each mesh size per string, a total of 126 net hauls were completed for each mesh size.

Table 3. Gillnet string and trawl sampling schedule conducted July 1 – 29, 2008.

Activity	Day														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
#Trawls Completed	1		2		2		2		2		2		2		2
#Gillnets Set	2		2		2		2		2		2		2		4
#Gillnets Hauled	0		2		2		2		2		2		2		2

	Day														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
#Trawls Completed		2		2		2		2		2		2		2	
#Gillnets Set		4		4		4		4		4		4		0	
#Gillnets Hauled		4		4		4		4		4		4		4	

At the conclusion of field work, four individual gillnets from each mesh size were measured to determine if nets had shown substantial within-net variation. Measurements of net length, overall height and tiedown height were not significantly different (Table 4).

Table 4. Mean gillnet measurements with 95% confidence intervals.

Gillnet measurement	Gillnet		
	10"	12"	14"
Net length (+/- CI)	297.3' +/- 4.5	301.3' +/- 6.9	296.6' +/- 2.8
Net height (+/- CI)	88.6' +/- 2.9	90.0' +/- 4.8	88.9' +/- 2.8
Tiedown height (+/- CI)	42.1' +/- 0.2	42.2' +/- 0.2	42.0' +/- 0.2

Monkfish Catch

Comparing the catch from each gillnet, the 12" mesh gillnet caught the most monkfish by total weight followed by the 10" mesh size (Table 5). By number, the 10" mesh caught the most monkfish and the 14" mesh size caught the least monkfish by both weight and number. The weight of trawl caught monkfish was similar to each gillnet but the total number of trawl-caught monkfish exceeded that from the gillnets by at least fourfold.

Table 5. Total monkfish weight (kg) and number by gear type.

Catch	Gear			
	10" gillnet	12" gillnet	14" gillnet	trawl
Weight (kg)	490.1	648.4	421.1	567.3
Number	136	106	52	571

A two sample paired t-Test indicated the 14" mesh gillnets caught significantly less monkfish by weight per haul than the 12" nets ($p = 0.012$) and significantly fewer monkfish per haul compared to the 10" nets ($p = <0.001$) and 12" gillnets ($p = <0.001$). The t-Test significance level for the weight per haul and number per haul was calculated to be 0.0167 using the Bonferroni method (Sokal and Rohlf 1995).

Retained monkfish made up the highest percentage of the total catch weight for all three gillnet gears (Table 6). The 12" mesh nets had the greatest percentage of kept monkfish while the 10" mesh had the lowest. Discarded monkfish made up only a small percentage of the total catch weight from the three gillnet mesh sizes. A total of eight monkfish were discarded from the three gillnets; six for quota restrictions, one for poor quality and one for being under the minimum size limit.

Greater than 50% of monkfish caught by any gillnet were female (Figure 6). Only a few monkfish were of unknown sex and these individuals were released alive as discards. The catch rate of male and female monkfish by weight was similar in the 10" mesh gillnets, but in the 12" and 14" mesh gillnets female monkfish dominated the catch. Similar results were recorded for numbers of monkfish caught in the gillnets (Figure 7) with the exception of the 10" mesh gillnets where more males dominated the catch.

Retained and discarded monkfish made up only 17.1% and 12.5% of the total trawl catch respectively (Table 6). Of the 474 monkfish that were discarded from the trawl catch, 456 (96.2%) were sublegal fish and the remaining monkfish discarded due to quota restrictions. Similarly to the gillnet catch, the trawl catch of monkfish was dominated by females (Figure 6 & 7) although monkfish of unknown sex were a major component of the trawl catch by weight and number.

Table 6. Total catch weight (kg) for each species by gear type.

Common name	Scientific name	10" gillnet		12" gillnet		14" gillnet		trawl	
		(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
Monkfish (kept)	<i>Lophius americanus</i>	480.9	48.0	635.1	68.4	419.6	53.0	327.1	17.1
Monkfish (discarded)		9.2	0.9	13.3	1.4	1.5	0.2	240.2	12.5
Dogfish, Spiny	<i>Squalus acanthias</i>	164.7	16.4	35.3	3.8	43.2	5.5	283.3	14.8
Flounder, American Plaice	<i>Hippoglossoides platessoides</i>	0.1	0.0					253.5	13.2
Flounder, Witch	<i>Glyptocephalus cynoglossus</i>	1.7	0.2					184.2	9.6
Skate, Thorny	<i>Amblyraja radiata</i>	86.6	8.6	75.8	8.2	196	24.7	175.4	9.2
Wolffish, Atlantic	<i>Anarhichas lupus</i>							128.2	6.7
Cod, Atlantic	<i>Gadus morhua</i>	75.5	7.5	35.7	3.8	15.2	1.9	125.5	6.6
Ray, Torpedo	<i>Torpedo nobiliana</i>							44.1	2.3
Flounder, Yellowtail	<i>Limanda ferruginea</i>							34.7	1.8
Skate, Smooth	<i>Malacoraja senta</i>	1	0.1	1.7	0.2			22.5	1.2
Lobster, American	<i>Homarus americanus</i>	139.3	13.9	117.8	12.7	82.8	10.5	21.0	1.1
Lumpfish	<i>Cyclopterus lumpus</i>	10.1	1.0			15.2	1.9	20.6	1.1
Haddock	<i>Melanogrammus aeglefinus</i>							11.8	0.6
Skate, Winter	<i>Leucoraja ocellata</i>							10.2	0.5
Hake, Silver	<i>Merluccius bilinearis</i>	1.1	0.1	1.1	0.1	0.4	0.1	9.4	0.5
Flounder, Winter	<i>Pseudopleuronectes americanus</i>							4.5	0.2
Pollock	<i>Pollachius virens</i>					12.3	1.6	4.5	0.2
Squid, Illex	<i>Illex illecebrosus</i>							4.5	0.2
Halibut Atlantic	<i>Hippoglossus hippoglossus</i>	5.5	0.5					2.7	0.1
Hake, White	<i>Urophycis tenuis</i>	17.9	1.8	11.6	1.2			2.3	0.1
Skate, Barndoor	<i>Dipturus laevis</i>	2.3	0.2			5.2	0.7	1.7	0.1
Crab, Jonah	<i>Cancer borealis</i>	0.6	0.1	0.8	0.1	0.8	0.1	0.8	0.0
Hake, Red	<i>Urophycis chuss</i>	2.1	0.2					0.6	0.0
Redfish, Acadian	<i>Sebastes fasciatus</i>							0.5	0.0
Flounder, Fourspot	<i>Paralichthys oblongus</i>							0.4	0.0
Sculpin, Longhorn	<i>Myoxocephalus octodecemspinosus</i>							0.3	0.0
Octopus sp.	<i>Octopoda</i>							0.1	0.0
Crab, Spider	<i>Majidae</i>	1.6	0.2	0.3	0.0				
Skate, Little	<i>Leucoraja erinacea</i>	1.1	0.1						
Total		1001.3		928.5		792.2		1914.6	

Monkfish Size Composition

Clear differences were observed in the size composition of monkfish captured in all gear types (Table 7). Boxplots of monkfish length grouped by gear type (Figure 8) indicated significant differences between all gear types with respect to the length frequency distribution (Figure 9). The trawl gear caught considerably smaller monkfish than any of the three gillnet mesh size gears (Table 8).

Table 7. The mean size of monkfish captured in all gear types +/- sd.

Size	Gear			
	10" gillnet	12" gillnet	14" gillnet	trawl
mean length (cm)	61.0 +/- 8.0	70.9 +/- 9.9	77.7 +/- 10.1	34.9 +/- 12.0
mean weight (kg)	3.6 +/- 1.8	6.1 +/- 2.7	8.1 +/- 2.7	1.0 +/- 1.5

Table 8. Comparison of monkfish length by gear type and two sample t-Tests ($\alpha = 0.05$).

Comparison	Median length (cm)	<i>t</i> value	<i>df</i>	<i>p</i> value
trawl v 10"	31 , 59	1.97	298	<0.001
trawl v 12"	31 , 71	1.97	168	<0.001
trawl v 14"	31 , 77.5	2.00	65	<0.001

For the gillnet data, natural log transformed monkfish lengths were tested for normality using the Shapiro-Wilk Test and outliers were removed until the 10", 12" and 14" data met the criteria of normality ($p > 0.05$) based on this test ($p = 0.142$, $p = 0.103$, $p = .417$ respectively). Two Sample t-Tests on natural log transformed monkfish lengths confirmed a concomitant increase in monkfish length with an increase in gillnet mesh size (Table 9).

Table 9. Results of Two Sample t-Tests ($\alpha = 0.05$) between monkfish length from all gillnet gears.

Comparison	Median length (cm)	<i>t</i> value	<i>df</i>	<i>p</i> value
10" v 12"	59 , 71	1.97	167	<0.001
10" v 14"	59 , 77.5	1.99	78	<0.001
12" v 14"	71 , 77.5	1.98	125	<0.001

Mean length/girth ratios and their associated 95% confidence intervals were determined for each gear type and sex (Figure 10). Trawl caught monkfish had a substantially smaller length/girth ratio than gillnet caught monkfish. Female monkfish showed a larger mean girth than males in all three gillnet mesh sizes (Table 10).

Table 10. Mean girth of male and female monkfish caught in the three gillnet gears.

gillnet mesh size	mean male girth (cm)	mean female girth (cm)
10"	46.0	56.3
12"	48.5	62.3
14"	49.5	66.4

Monkfish Gillnet Size Selectivity

Catches were not adjusted for effort for selectivity analysis as gear characteristics and soak time were similar. Fitting of pooled data (all lengths) resulted in highly similar fits for all five curves; GOF measures ranged from 0.93 to 0.99, also indicating that no model was over-dispersed ($GOF > 1.0$). Subsequently, all fourteen trips were individually fit to each curve, and for each trip, the best fit was determined. Bimodal curves provided one or two best fits, but most bimodal curves did not converge or resulted in inappropriate fits. The gamma model only provided one best fit for a trip.

The gamma and bimodal distributions were subsequently eliminated from model selection because REML results (which includes between-haul variation) for these models did not converge. The three remaining models (normal scale, normal location, and lognormal) were able to incorporate all trips. While all three of these models appeared adequate, AIC values for the lognormal distribution were lowest and were selected as the best model. Additionally, the lognormal distribution provided the best fit in another recent similar monkfish gillnet selectivity study in the region (Pol et al. 2009).

Lognormal curves were fit to data from all trips, and showed some typical between-trip variability (Figure 11). Pooled lengths and the REML curve were also plotted, and showed differences in location and in scale. Final model results for the lognormal distribution using the REML resulted in modal values of 61.1, 73.3, and 85.5 cm for the 10", 12", and 14" mesh gillnets respectively. Figure 12 displays the REML selection curves plus the observed proportion of the catch at length for each mesh sizes.

Bycatch

Of the three gillnet mesh sizes, the 12" gillnets had the lowest proportion of total bycatch by weight (31.6%) while the 10" gear had the highest (52.0%) (Table 6). The bycatch

consisted mainly of spiny dogfish, American lobster, thorny skate and Atlantic cod. There was an inverse relationship between the catch weight American lobster and Atlantic cod and increased gillnet mesh size, but this was not significant (Table 11). The weight per haul of spiny dogfish was greatest in the 10" gillnets and the weight per haul of thorny skate was greatest in the 14" gillnets.

Table 11. Paired Two Sample t-Test ($\alpha = 0.05$) results comparing weight per haul of the four dominant bycatch species in the gillnets. * = $p < 0.05$

Species	gillnet comparison	<i>p</i> value ($t = 2.02, df = 41$)
Atlantic cod	10" v 12"	0.212
	10" v 14"	0.075
	12" v 14"	0.195
American Lobster	10" v 12"	0.505
	10" v 14"	0.056
	12" v 14"	0.060
Spiny dogfish	10" v 12"	0.001 *
	10" v 14"	0.003 *
	12" v 14"	0.669
Thorny skate	10" v 12"	0.654
	10" v 14"	0.021 *
	12" v 14"	0.004 *

Trawl bycatch composition varied greatly from the gillnet gear (Table 3). The trawl data also showed a much higher percentage of bycatch by weight (82.9%) than the gillnet data. The catch composition for the trawl included the four prominent bycatch species seen in the gillnets but also included large amounts of American plaice, witch flounder and Atlantic wolffish.

DISCUSSION

Monkfish Catch & Bycatch

The catch rate of monkfish by weight was highest using the 12" gillnet compared to the other gillnet mesh sizes, confirming a preference by the fishing industry to use 12" gillnets despite a legal minimum size of 10"¹. From a commercial fishing perspective where the goal is to maximize the catch per unit effort, this mesh size would appear to be optimal for targeting monkfish.

From a management perspective, 12" gillnets are also most favorable because they have the lowest overall bycatch rate of all three tested mesh sizes, and a reduction of bycatch, especially for species of concern, presumably should result in positive impacts on their overall population. Decreases in catches of Atlantic cod and thorny skate may be especially critical: "overfishing" (fishing mortality is over targets) is currently occurring on the Gulf of Maine stock of cod (NEFSC 2008) and thorny skate is currently considered to be "overfished" (stock levels are below targets) (NEFSC 2007b).

The monkfish population also benefits from the use of 12" gillnets over the legal minimum mesh size of 10". We can presume the survival of smaller monkfish is improved by the reduction of discarding of these smaller fish. While monkfish discard mortality is uncertain and no data exists for individual fisheries, discard survival in limited studies ranged from 8 to 57% (NEFMC 1998). Decreased mortality of small monkfish implies increased stock size and reproductive potential for the monkfish stock. Our results support conclusions by Thangstad et al. (2006) in Norwegian waters, who suggested a change towards only using large-meshed gillnets could increase the long-term yield of monkfish species by 20-25%.

Our data showed a disproportionate amount of female to males monkfish captured in the 12" and 14" mesh size gillnets. Superficially, these results would indicate that larger mesh gillnets could have a negative impact on the overall population's sex ratio. However, the maximum ages for the two sexes appear to be different with females living longer (Armstrong et al. 1992, Richards et al. 2008). Since monkfish growth is linear, regardless of age (Richards et al. 2008), the capture of mostly females in 12" and 14" gillnets is due to larger sizes of females of greater longevity. Armstrong et al. (1992) demonstrated a linear increase in fecundity with total length for monkfish; therefore, the removal of these larger, older females may be affecting the overall reproductive potential of monkfish.

The trawl hauls conducted were 20 minutes in duration which is much shorter than normal commercial fishing practices. The purpose of these tows were to provide a measure of the full range of monkfish sizes as well as the presence of other species in the immediate area of the gillnets. While the trawl catch data was not directly comparable to

¹ This practice can be confirmed through observer data. From 2004 through 2007, 83.1% of the gillnet hauls recorded as targeting monkfish used 12" mesh size in the Northern Management Area. Source: Gina Shield, NOAA/NMFS/NEFSC Fisheries Sampling Branch Woods Hole, MA 02543.

the gillnet data due to effort differences, the information clearly showed that the trawl catch was considerably different than the gillnet catches. There was a wider array of species caught and the percent catch composition differed dramatically. This would indicate that gillnets can be fished more selectively for monkfish than trawl gear. From a conservation perspective, this is quite desirable as improved species selectivity allows for the capture of the target species while reducing the catch of non-target species, preferably unharmed (Nichols et al. 2001).

Monkfish Size Composition

Not only did the trawl data indicate differences with the gillnets with respect to species composition but also in the size composition of monkfish caught between the two major gears. This study confirmed what fishermen have reported in the past, that gillnets catch larger monkfish than trawls operating in the same areas (NEFMC 1998). Observed otter trawl and 12" gillnet trips conducted between 2004 and 2007 from the overlapping NMFS statistical area 513 also indicate that the trawl fishery captures smaller sized monkfish than the gillnet fishery catches (Figure 13). Fishing gears that are designed to capture a desired minimum length or size can have a beneficial impact as they allow juvenile fish to escape unharmed and potentially grow to reproductive size (Nichols et al. 2001).

The smaller sized monkfish catches in the trawl fishery has been recognized through the Federal regulations. All trawl vessels that are targeting monkfish using a monkfish day at sea must use a net with a minimum mesh size of 10" square or 12" diamond throughout the codend², in order to reduce bycatch of marine species including smaller sized monkfish (NEFMC 1998).

Monkfish girth measurements were different between the trawl and gillnet caught fish. These differences may be accounted for by handling practices aboard the vessel. All trawl caught monkfish were taken from the catch and directly measured while all gillnet caught fish were first stunned with a hammer to facilitate removal from the gear before measurements. Figure 14 demonstrates the results; trawl caught monkfish tended to be in a flexed and rigid state whereas the gillnet caught fish had a more relaxed body character. This rigid and flexed state of the trawl caught monkfish caused the opercular region where the measurements were taken from to be flared outward resulting in larger girth measurements.

The difference in girth measurements between gears complicates comparisons. Within gears, comparisons can be made. No differences were detected in the length/girth ratio between male and female monkfish caught in the trawl gear. Recent maturity information on monkfish indicates that the length at 50% maturity in the Northern Management Area is 40 cm for females (NEFSC 2002). The average size female monkfish caught in the trawl gear was 59.6 cm. This would indicate that many of the females caught had only recently become mature and would not have the massive egg

² "Monkfish regulated mesh areas and restrictions on gear and methods of fishing." Title 50 Code of Federal Regulations, Pt. 648.91 (c)

veils that swell the body as seen in the older and larger females. Therefore, the male and female length/girth ratios should be similar in trawl caught monkfish.

For the three gillnet mesh sizes, female monkfish averaged a larger girth than the males, but length/girth ratio differences were noted only in the 10" and 12" gears. Because the 95% confidence intervals are inversely proportional to the sample size (Sokal and Rohlf 1995), the low number of males (2) taken in the 14" gear produced a wide confidence interval around the mean length/girth ratio. It is believed that a larger sample size of males in this gear would have resulted in a higher mean length/girth ratio and tighter confidence intervals that would have been distinct from the female data. The larger sized and thus older females caught in the gillnets were developing massive eggs veils as part of their biological life cycle. It is probable that these eggs veils caused the overall body shape to swell and distend out resulting in the difference between males and females in the 10" and 12" gillnet gear.

Monkfish Gillnet Size Selectivity

Baranov (1914, cited in Hamley 1975) argued that of the three primary ways fish are caught in gillnets (wedging, gilling, and tangling), only the first two could depend on mesh size. Some unusually-shaped fish do not show size-selectivity in gillnets (for example, paddlefish *Polyodon spathula* (Scholten and Bettoli 2008). The monkfish's unusual morphology and bottom-affinitive habits, coupled with our observations of its entanglement in gillnets, suggest that monkfish also might not show size-selectivity. However, our results show that monkfish do in fact exhibit size selectivity in tiedown gillnets with fish lengths increasing with mesh size. These results support other research efforts in the area (Pol et al. 2009) that also found size-selectivity for monkfish in gillnets. Potentially, the results from this study could be used in monkfish stock assessment; however, the relatively small number of monkfish captured (294 in gillnets) indicates that the results are perhaps not sufficiently robust for broad application. These results do appear to be similar to preliminary results from the similar study that found modal lengths of 62, 75, and 87 cm for 10", 12" and 14" mesh gillnets respectively from the Southern Management Area (Pol et al. 2009).

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PARTNERSHIPS

The partnership between project participants was exceptional. Capt. Stephen Lee approached GMRI with the belief that larger gillnet mesh sizes may be effective in capturing monkfish while reducing the amount of bycatch. The potential for this application of larger meshed gillnet gear would help in developing a cleaner monkfish fishery, particularly with respect to the bycatch of species such as cod and others where overfishing is a concern. The resultant proposal developed by Shale Rosen incorporated Capt. Lee's ideas with key research priorities for monkfish.

Throughout the field component the crew, Capt. Lee and mate Mike Pawluk provided researchers with key insights into the monkfish fishery and provided extraordinary support to the scientific personnel aboard their vessel. They also proved adept at catching monkfish throughout the study period which provided a significant number of monkfish to sample.

One major outcome of this project was the mutual respect fostered between all project participants. So much so that the F/V Kirsten Lee and its crew has since participated with GMRI on a second research project involving bycatch in the shrimp fishery. There have also been several discussions of other future research project ideas between GMRI and Capt. Lee and we are confident that future collaborations will result.

The cooperation between GMRI and Massachusetts Dept. of Marine Fisheries proved to be excellent. As with past cooperative work between the two institutions, there was always an open dialogue and a free exchange of ideas from proposal development to reporting of project findings. It is expected that GMRI and Mass DMF will again work closely together in the future to assist the fishing industry with the many gear technology issues facing them.

IMPACTS / APPLICATIONS

The selectivity and bycatch information from this study would benefit many in the monkfish community. The selectivity information would be useful to gillnet fishermen who are interested in using different mesh sizes to target monkfish. The biological data would provide NMFS scientists an insight into the impacts of commercial fishing on the monkfish population. This information would also provide members of the Monkfish Advisory Panel and Monkfish Oversight Committee of the New England Fishery Management Council much needed information on bycatch and selectivity for the four gear types.

RELATED PROJECTS

This study was not a part of any other work.

PUBLISHED REPORTS / PAPERS

No reports or papers have yet been published as a result of this study.

PRESENTATIONS

Poster:

Daniel J. Salerno, Steve Eayrs, Adam Baukus, Nicole Stephens (GMRI), Stephen Lee (F/V Kirsten Lee) & Michael Pol (MA DMF)

Analysis of Size Selectivity and Bycatch in the Gillnet Fishery for Monkfish

Maine Fishermen's Forum

March 5 – 7, 2009

Rockland, Maine

STUDENT PARTICIPATION

Gary Robinson, an undergraduate student from Newcastle University UK and a summer intern at GMRI, assisted with field sampling (Figure 15) gaining insight into the monkfish fishery as well as catch sampling.

FUTURE RESEARCH

Future work should include more selectivity and bycatch research with the different mesh size monkfish gillnet gears similar to what has been completed here. While the outcomes from this project showed clear and reasonable results, the project itself was limited in scope with respect to season and location. Our recommendation would be to continue this work in other areas where the monkfish fishery occurs and during other seasons when the fishery is taking place (e. g. Mid-Atlantic region spring fishery or Southern New England Region winter fishery) to see if results are analogous.

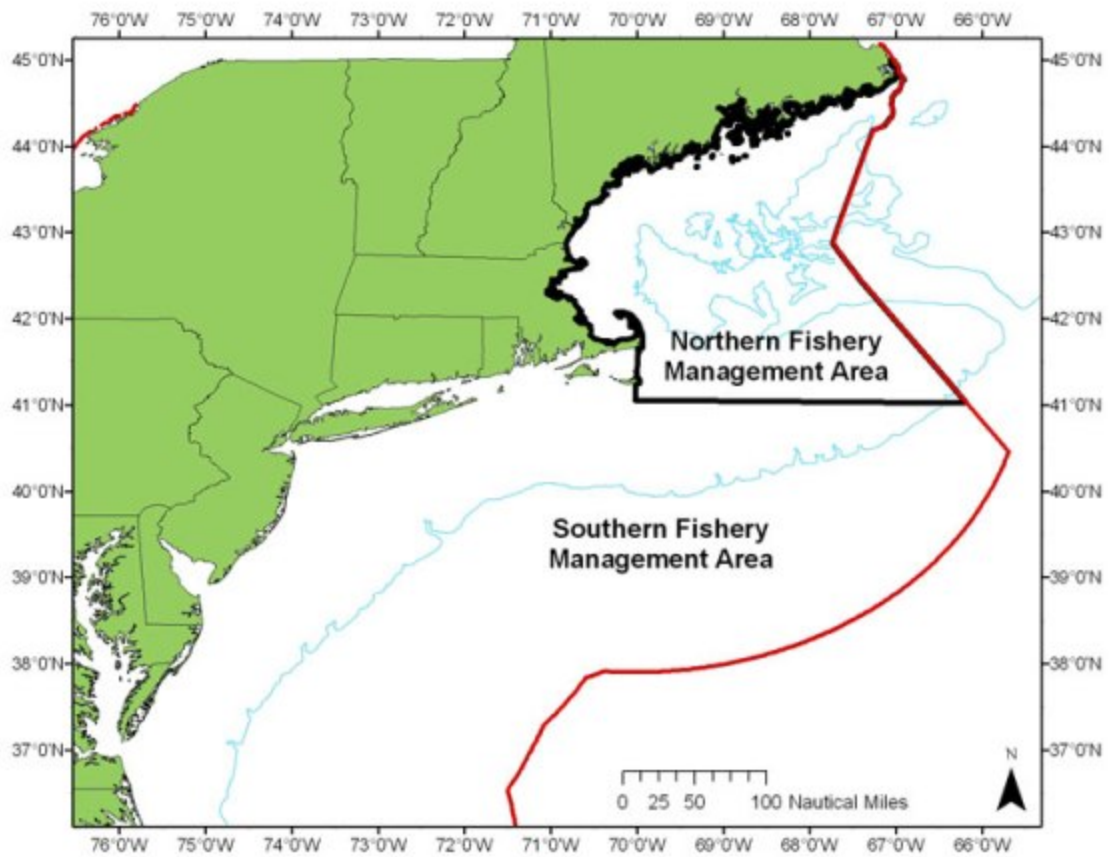


Figure 1. Map of the Northern and Southern Management Areas for monkfish.³

³ Courtesy of NOAA Fisheries Northeast Regional Office.
(<http://www.nero.noaa.gov/nero/fishermen/charts/monk1.html>)

(a) trawl net



(b) gillnets



Figure 2. The F/V Kirsten Lee, outfitted for fishing both otter trawl (a) and gillnets (b).

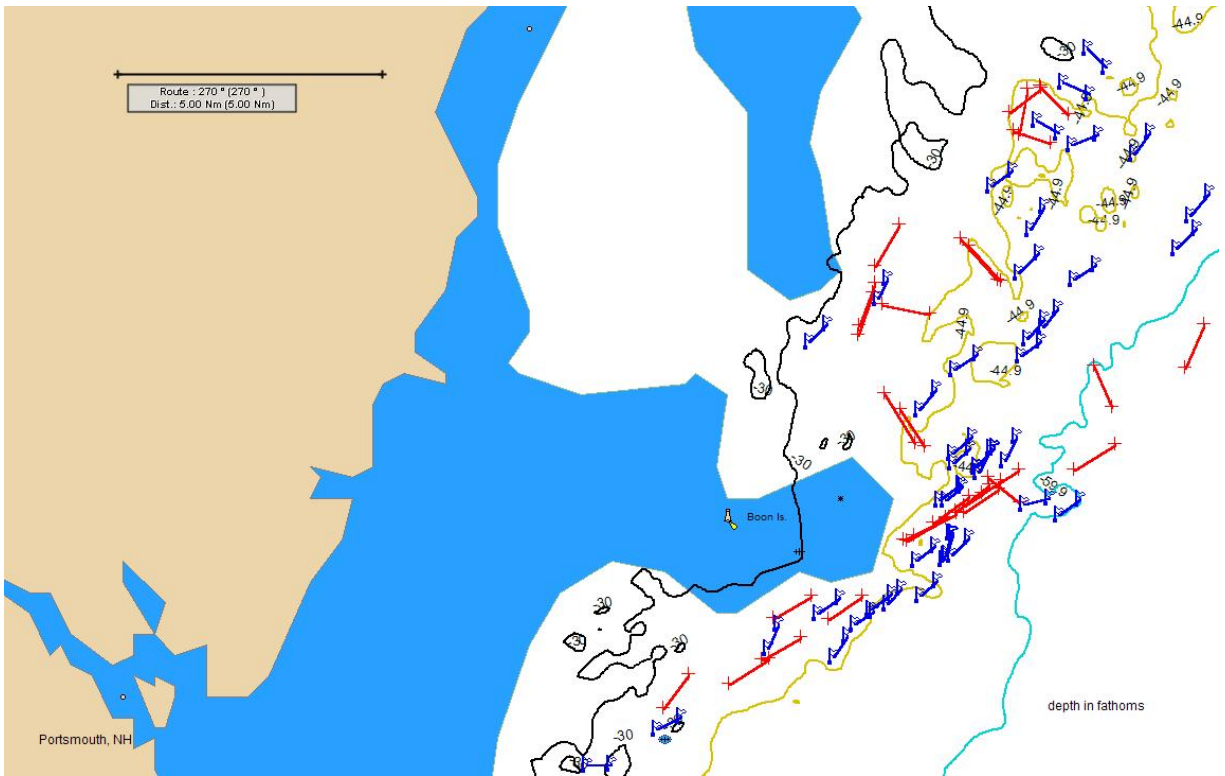
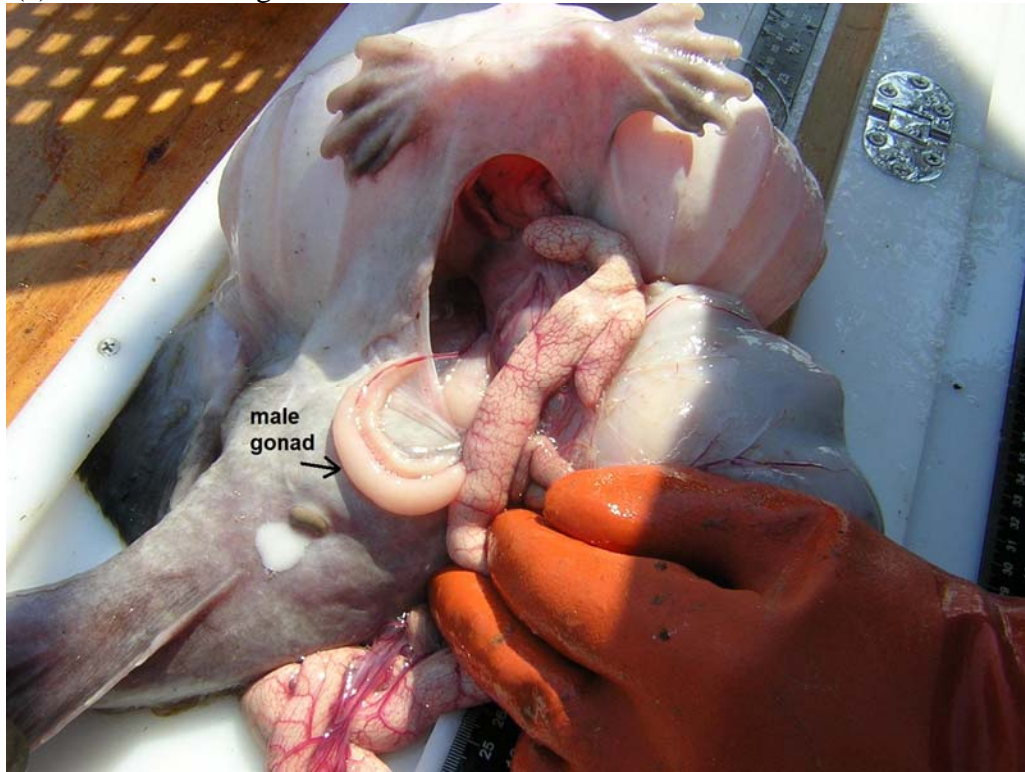


Figure 3. Monkfish trawl and gillnet study area. (Gillnet sets are blue [flag] and trawl hauls are red [+].)



Figure 4. Location of girth measurements for monkfish.

(a) male monkfish gonad



(b) female monkfish gonad



Figure 5. Male (a) and female (b) monkfish gonads.

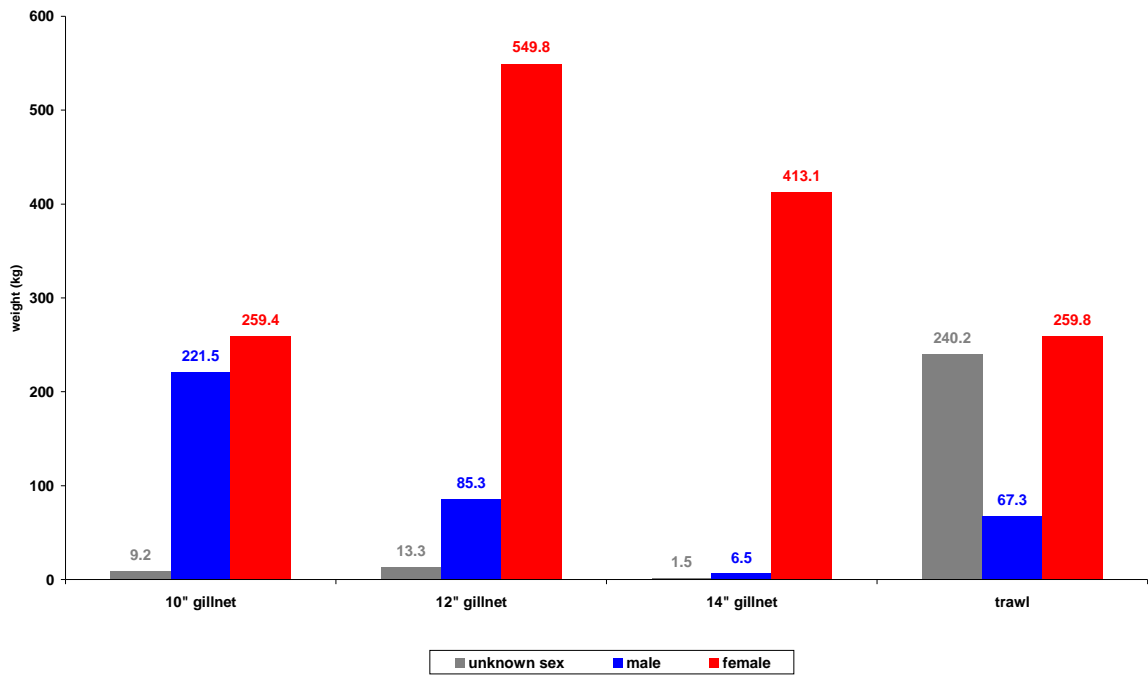


Figure 6. Total weight (kg) of monkfish separated by sex for all gear types.

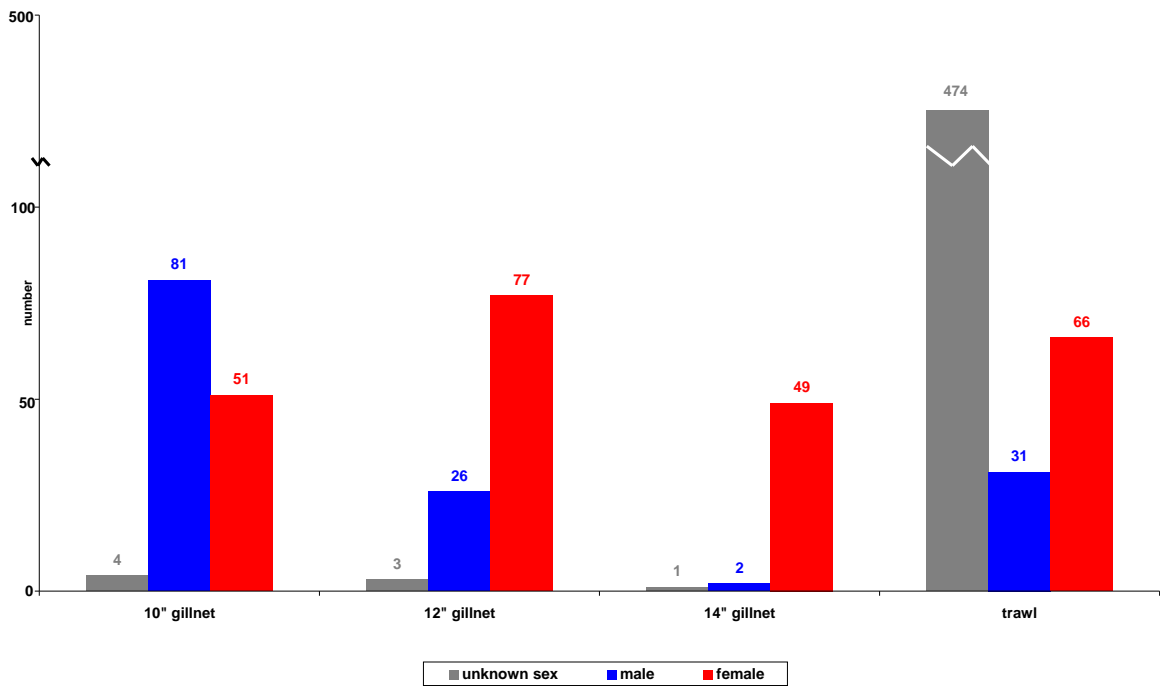


Figure 7. Total number of monkfish separated by sex for all gear types.

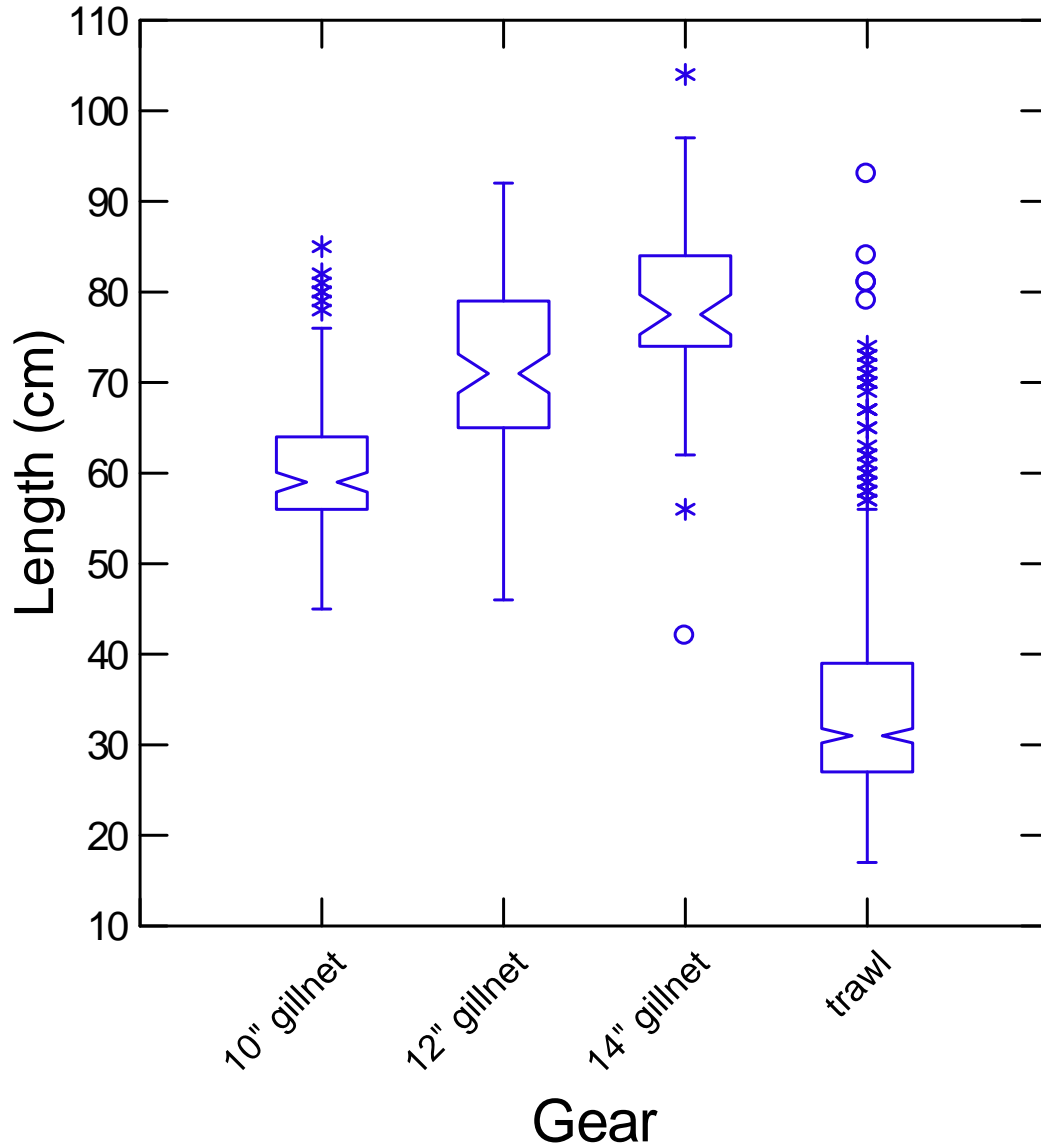


Figure 8. Boxplots of lengths of monkfish by gear type. (Whole monkfish minimum landing size = 43.2 cm.)

- Notches are at the median and indicate approximate 95% confidence intervals.
- Box indicates 1st to 3rd inner quartile range (IQR).
- Whiskers indicate range of values less than 1.5 times IQR.
- Stars (*) indicate values outside of 1.5 times IQR.
- Circles (o) indicate values outside of 3 times IQR.

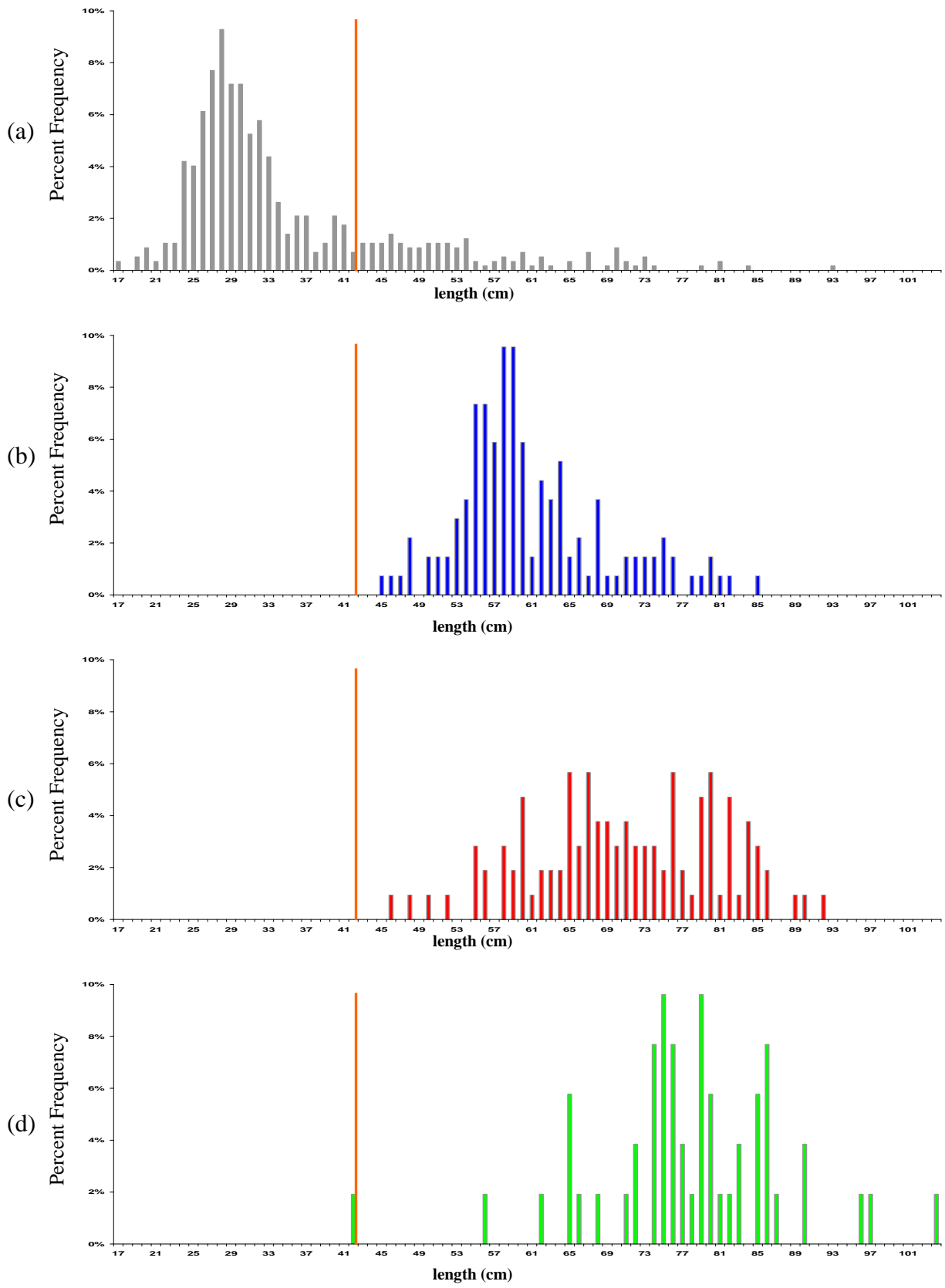


Figure 9. Monkfish percent length frequency distribution caught in the trawl net (a), 10" gillnets (b), 12" gillnets (c) and 14" gillnets (d). (Orange line indicates the minimum size limit for whole monkfish at 17" or 43.2 cm.)

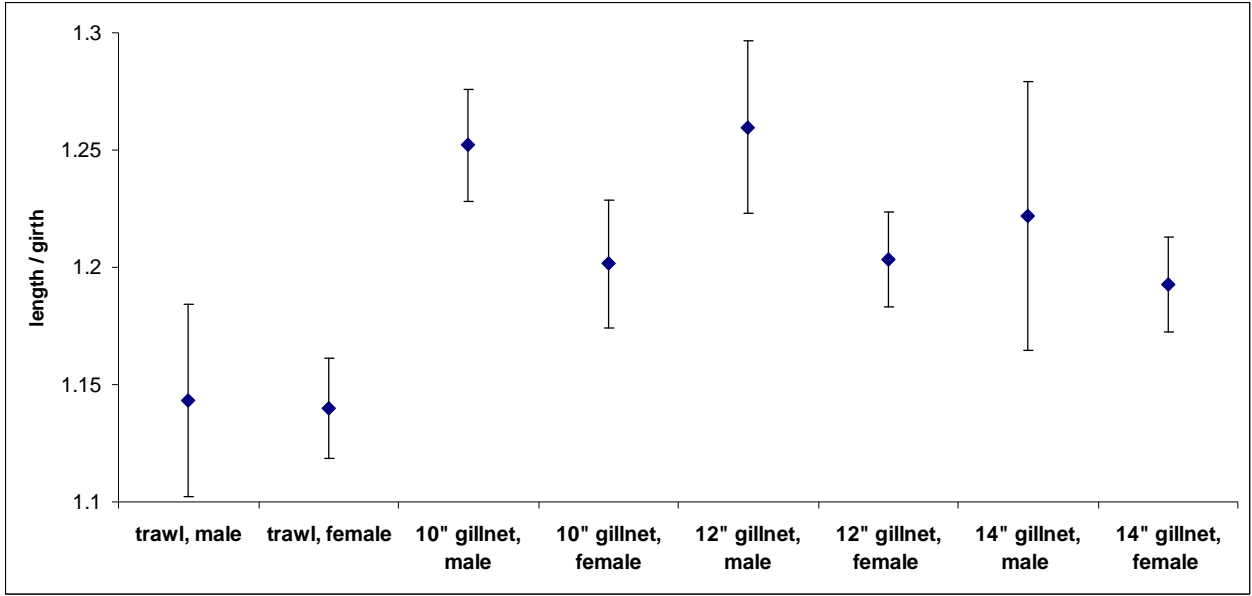


Figure 10. Mean length/girth ratios and their associated 95% confidence intervals for monkfish by gear type and sex.

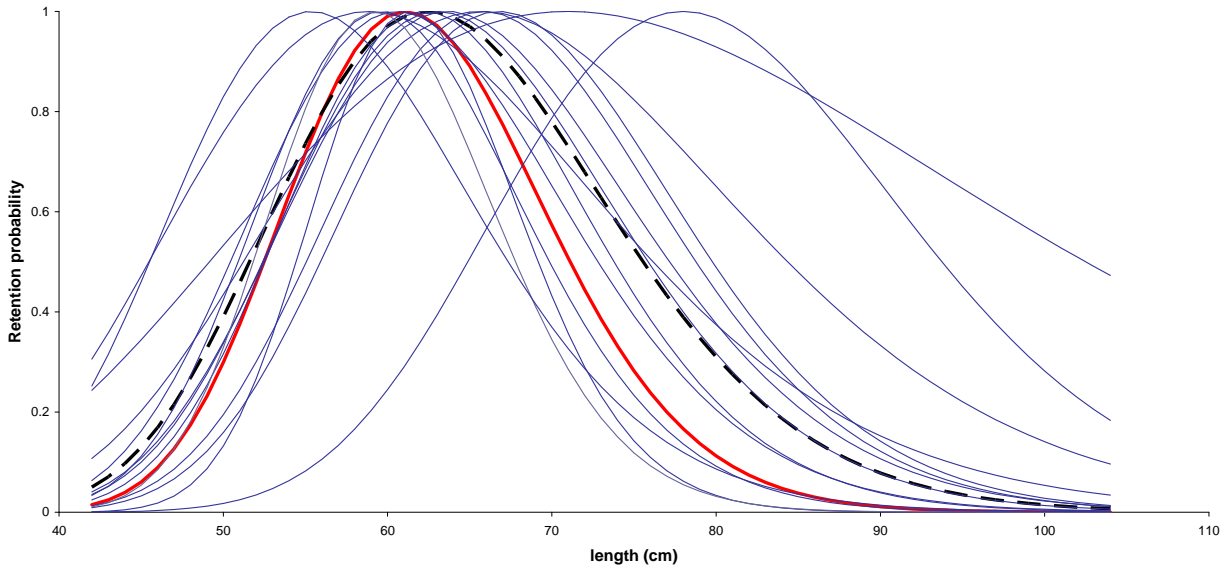


Figure 11. Lognormal curves fit to monkfish catches in 10" mesh for individual hauls (thin lines), all lengths pooled together (thick dashed line) and all trips (thick solid line). (The "all trips" line incorporates the variation between hauls and is considered the best fit.)

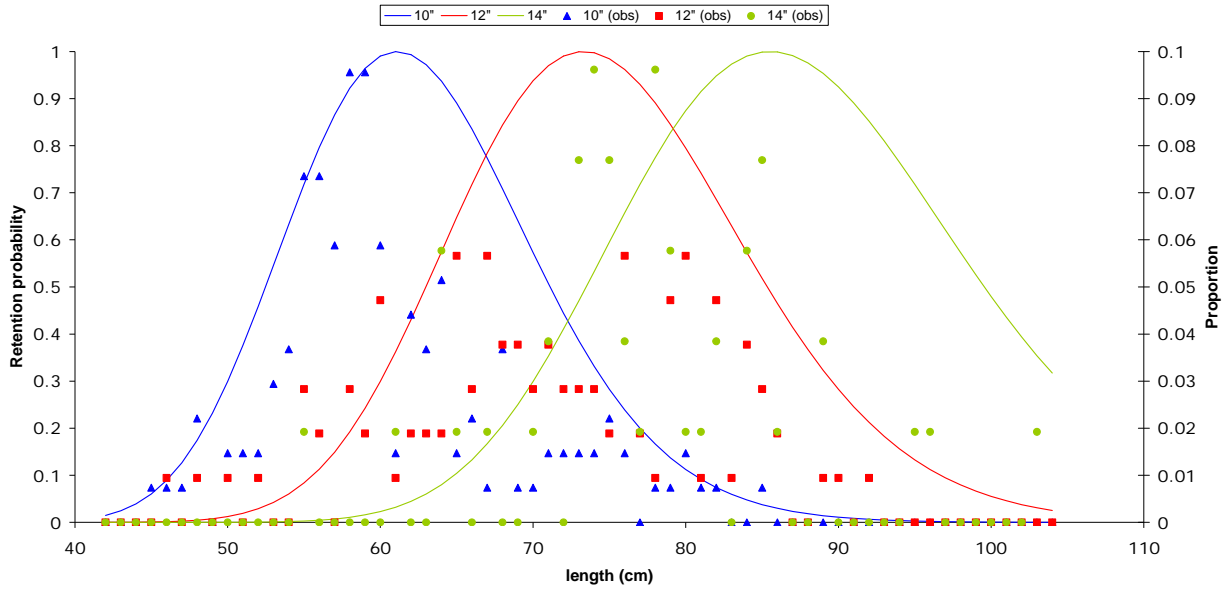


Figure 12. Lognormal curves for all mesh sizes fitted from individual trips. (Individual points are the observed proportion of catch-at-length for each mesh size.)

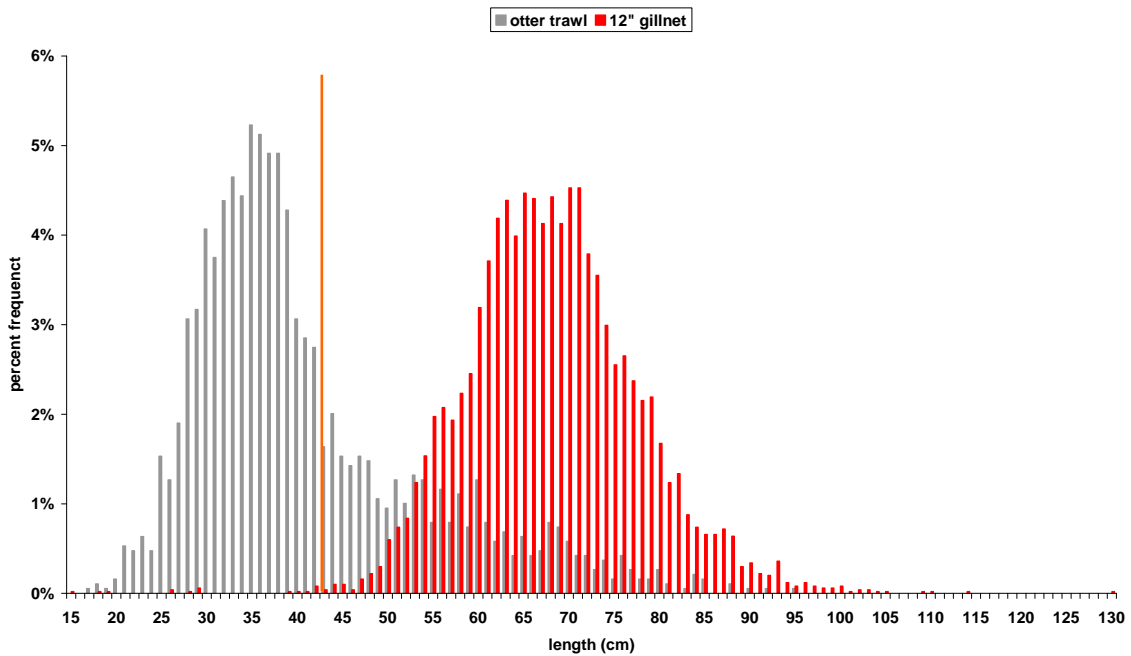
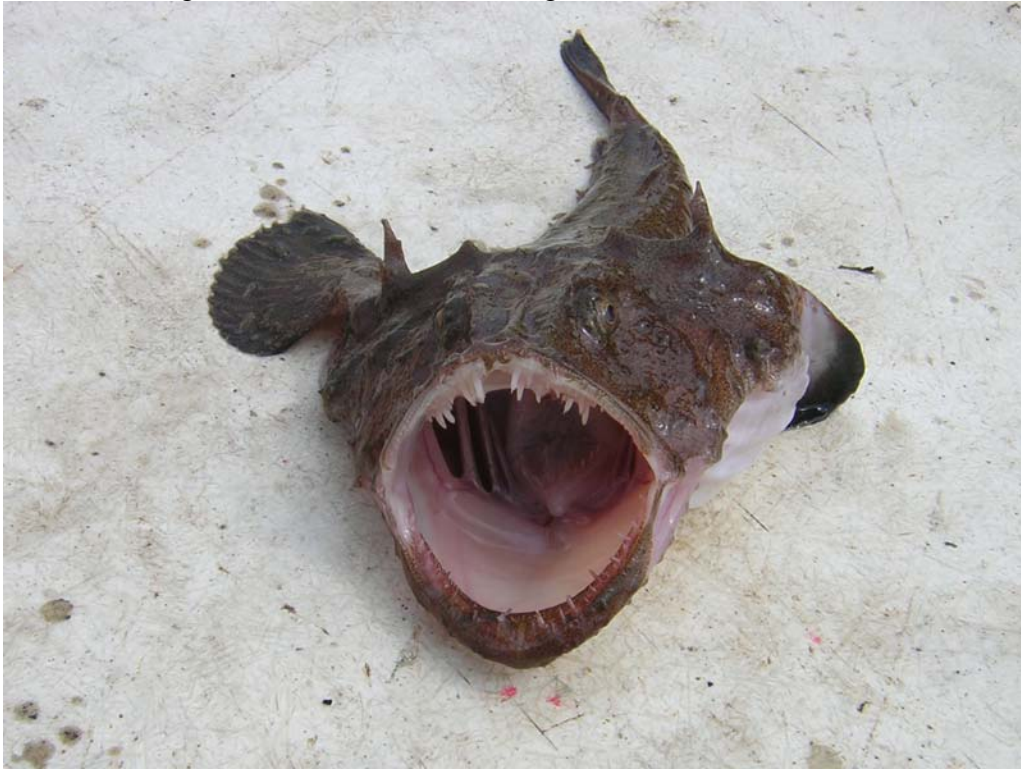


Figure 13. Percent length frequency for monkfish collected from observed otter trawl and 12" gillnet trips conducted between 2004 and 2007 from statistical area 513.⁴

⁴ Gina Shield, NOAA/NMFS/NEFSC Fisheries Sampling Branch Woods Hole, MA 02543.

(a) trawl caught monkfish – flexed and rigid



(b) gillnet caught monkfish - relaxed



Figure 14. Body character of trawl (a) and gillnet (b) caught monkfish.

(a)



Figure 15. Gary Robinson, GMRI summer intern, posing with a monkfish.