BYCATCH REDUCTION IN THE
DIRECTED HADDOCK BOTTOM TRAWL FISHERY

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ABSTRACT

The effects of employing a large mesh faced (top, bottom, and side wings) bottom trawl designed to capture haddock while reducing the bycatch of cod as well as other species was investigated. This experimental net, named the "Eliminator Trawl," exploits the differences in fish behavior. Two vessels, F/V *Iron Horse* and F/V *Sea Breeze*, conducted side-by-side comparison hauls with one vessel towing the control net (currently regulated specifications) and the other towing the experimental net. A total of 100 successful tows were completed. All species captured were weighed for total weight. Haddock, cod, and the majority of the flounders caught were measured. The "Eliminator Trawl" significantly reduced the catch of stocks of concern including Georges Bank (GB) cod, GB yellowtail flounder, GB winter flounder, witch flounder, and American plaice. Other species such as monkfish and skate also showed significant decrease in catch in the experimental net. In addition, the catch of GB haddock, the target species, did not differ significantly between nets. The results of this study indicate that the "Eliminator Trawl" would be an efficient tool in the B Days-at-Sea Program as well as a Special Access Program as it appears to meet the minimum bycatch requirements to be considered for both these programs.

INTRODUCTION

Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) support important commercial fisheries. Both are managed under the New England Fishery Management Council's Northeast (NE) Multispecies Fishery Management Plan (FMP) (NEFMC 1993), which recognizes two principal stocks for each, Georges Bank (GB) and the Gulf of Maine (GOM) (Mayo 1995; Mayo and O'Brien 1998; Cargnelli et al. 1999). Under this FMP cod and haddock are included in a complex of 19 groundfish stocks which have been managed by time/area closures, gear restrictions, minimum size limits, and since 1994, direct effort controls including a moratorium on permits and days-at-sea restrictions (Brown 2000; Mayo and O'Brien 2000). The goal of the management program is to reduce fishing mortality to levels which will allow stocks within the complex to initially rebuild above minimum biomass thresholds, and ultimately, to remain at or near target biomass levels (Brown 2000; Mayo and O'Brien 2000). In the most recent assessment, Georges Bank cod were declared overfished and overfishing was determined to be occurring. Georges Bank haddock was overfished but overfishing was not occurring (Mayo and Terceiro 2005).

This study focuses on the reduction of cod in the haddock catches, as well as other key bycatch species. Haddock and cod are regularly caught together and due to the status of the stocks and the rebuilding objectives for cod, there are constraints on the harvest of haddock (TRAC 2006). There is a zero bycatch tolerance for the cod fishery, and therefore once the quota of cod is attained, the haddock fishery is closed. In most years, this means that the total allowable catch (TAC) is not reached resulting in a loss of revenue to the fishermen (Table 1). The basic impact of the research described in this report is to provide fishermen an alternative means of harvesting haddock without impacting the cod stock.

For decades, bycatch has been an issue in trawl fisheries and consequently much effort has been directed to improve the selective performance of trawls. Research focuses on reducing both the bycatch of undersized fish as well as non-target species (Engås 1994). Reduction of undersized fish has been accomplished using mesh size regulations; however, recently there has been a trend towards the development of species-selective trawl gears (Isaksen and Valdermarsen 1994).

A trawl does not simply filter fish out of the sea passively; instead there is an interaction between trawl and fish (Main and Sangster 1981; Thomsen 1993). This interaction is complex involving both the fishing gear performance and fish behavior. To improve the selectivity of trawls, it is necessary to isolate those features of fish behavior and fishing gears which determine the efficiency of the capture process (Main and Sangster 1981). Different species of fish show clear differences in their reaction behaviors (Glass and Wardle 1996). By exploiting these behavioral differences of fish in response to specific components of the gear, trawls can be developed to separate the catch by species (Wardle 1993).

Separation of species becomes difficult when dealing with fish that have virtually identical shape and size; therefore, the knowledge of fish behavior is a very important component in the development of more selective gear. For example, cod and haddock are bottom fish with similar shapes. However, it has become clear that the separation of cod and haddock is possible due to the different behaviors they exhibit when entering the net (Main and Sangster 1981). Cod remain low near the seabed and enter the trawl close to the groundrope, whereas haddock rise when entering a bottom trawl, high over the groundline into the top part of the net mouth, and enter the trawl in the upper half. In addition, flatfish also remain low when entering the net. The use of these behavior differences may result in the development of more selective nets that allow for greater effective management of fish stocks (Main and Sangster 1981).

Species-selective trawls are useful in multispecies fisheries regulated with quotas where it is sometimes necessary to restrict fishing effort when the quota of one species is taken. This can be done by either stopping all fishing in the relevant area to avoid overfishing of the stocks of concern or permitting a certain amount of bycatch of the protected species while fishing for others (Isaksen and Valdermarsen 1994). These quotas impose pressures on fishermen to be more precise in their fishing techniques (Glass and Wardle 1996) and it is therefore beneficial for the fishermen to use a technology where the bycatch is minimal and within legal limits.

The industry principal investigators of this study designed and field tested a trawl to eliminate cod and other bycatch from haddock catches prior to the development of this study. The fishermen utilized the flume tank facility at the Centre for Sustainable Aquatic Resources located at the Marine Institute of Memorial University of Newfoundland to make adjustments to the original design. The modified net, which has been named the "Eliminator Trawl" by the net manufacturer, Superior Trawl, was then built for this study. The collaborative nature of this study makes it truly a success. Through collaboration between the fishing industry and the URI/RISG Fisheries Extension Program, the project was developed and funded. The results presented herein are an outcome of this collaboration.

Project Goals and Objectives

The primary goal of this study is the reduction of cod in the catches of haddock. In addition, the reduction of other bycatch species was investigated. The main objectives were:

(1) To test the effectiveness of an experimental trawl on its ability to reduce the catches of cod, as well as other bycatch, in the targeted haddock fishery.

(2) To promote collaborative research directed by fishermen.

METHODS

Project Design

Field Methods

A bottom trawl catch characterization study was conducted aboard commercial fishing vessels, targeting haddock using the "side-by-side" towing method comparing the control net (constructed to current legal specifications) with the large mesh experimental net. Side-by-side towing also referred to as parallel fishing, parallel tow technique, or parallel haul method, involves two vessels fishing on the same ground at the same time, the only difference being the design of the trawl being towed. The side-by-side method greatly reduces the effects of the many uncontrolled variables.

Two fishing vessels based in Rhode Island participated in this study; the F/V *Iron Horse* and the F/V *Sea Breeze*. The two vessels were equivalent in length, horsepower, and fishing capacity. Each vessel has 675 HP and each vessel used 84 type 3 Thyboron trawl doors, as well as identical control and experimental trawls.

Sampling was done on Georges Bank in and around Closed Area I (CA I) (Figure 1). Depths for the CA I tows ranged from 20 to 111 meters. Those tows conducted outside CA I had depths ranging from 25 to 57 meters. An Exempted Fishing Permit was obtained so that fishing could occur in CA I. Four fishing trips were conducted (June, November, and December 2005; April 2006). A total of 5 days of fishing were conducted in June and November 2005, and 2 days in December 2005 (3 days were lost to inclement weather); all three of these trips were conducted in CA I (Figures 2-4). For the April 2006 trip, a total of 7 days of fishing were conducted on Georges Bank outside CA I (Figure 5). A total of 107 comparison tows were conducted, however, due to hangs and gear damage, only 100 were used in the analysis.

On each day of sampling, the two vessels towed side-by-side with one vessel towing the control net and the other the experimental net. Tow duration was 1.5 hours and the vessels switched nets after every 3 tows. All tows began and ended at the same time which was coordinated by the vessel's captains. The amount of wireout was 150 fathoms (~275 m) in CA I. Wireout for tows outside CA I changed depending on the depth of the water and ranged from 100 to 175 fathoms (~180 to 320 m). Door spread data was not recorded but was monitored by the fishermen to verify that the doors were upright and spreading the net properly.

All catch was sorted by species into totes and baskets. Total weights for all species were recorded in kilograms to 2 decimal places. For each tow, either all of the haddock and cod or a random subsample was measured (to nearest cm). Subsampling amounts were no less than 15% of the total catch of each species. Flounders including yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuornectes americanus*), witch flounder (*Glyptocephalus cynoglossus*), and American plaice (*Hippoglossoides platessoides*) were also measured. Fork length or total length was measured depending on the species, based on standard NOAA Fisheries fish sampling protocols. The subsampled lengths were adjusted to take in account the actual weight of the species.

Two sea samplers were onboard each vessel to weigh and measure fish. Samplers were from the URI/RISG and the NOAA Fisheries NEFSC. A Scantrol FishMeter and Marel M1100 Marine Scale were used to sample the fish. Both were connected to a Shark Marine Rocky laptop so that data was directly sent to the computer. After each tow, data was then sent to the NOAA Fisheries server. The NOAA Fisheries NEFSC audited the data for quality assurance.

Trawl Design

The four seam control net (C) was constructed using legal 6 inch polyethylene webbing, with a fishing circle of 392 x 6 inches, and a hanging line length of 3600 cm. Twenty fathom ground cables and twenty fathom bridles were used in the control trawl protocol. Vertical lift was achieved by using seventy-two 8 inch center hole floats on the headrope. The sweep consisted of two 16 inch rockhopper discs and five 16 inch floppy discs per bight in the center, with the wing sections having two 14 inch rockhopper discs and five 14 inch floppy discs per bight (Figure 6).

The four seam experimental net (E) or "Eliminator Trawl" was constructed with large mesh (240 cm) jibs, wings, bunts, and first bottom belly; the square and second bottom belly of 80 cm webbing; each of those sections was followed by 20 cm webbing sections; and the last top and bottom bellies were 6 inch webbing (Figures 7 and 8). The side panel mesh sizes were the same configuration as the top sections. The fishing circle was 315 x 40 cm and the hanging line was 3600 cm. Twenty fathom ground cables and thirty fathom bridles were used with the experimental net. Vertical lift was attained by using a 3-panel kite with each panel having an area of one square meter. Electronic measurements taken during the June 2005 trip determined headrope heights between 5 and 6 fathoms. The rockhopper sweep was constructed with one 16 inch disc per bight in the center, one 14 inch disc per bight alone the wings near the center, and one 12 inch disc per bight to the wing ends (Figure 9).

Analysis

Weight

Weight data for all species was determined to be non-normal by the Shapiro-Wilk *W* statistic and therefore nonparametric paired comparison tests were conducted to test for differences between weight of fish in the experimental and control nets. The sign test was calculated on the difference between the control and experimental catch weights for each tow for each species using PROC UNIVARIATE in SAS 9.1. The hypothesis tested was:

H_0: the mean weight in the control and experimental nets is the same, $\mu_1 = \mu_2$.

H_A: the mean weight in the control and experimental nets is not the same, $\mu_1 \neq \mu_2$.

The sign test counts the number of positive and negative signs among the differences. Therefore, the hypothesis that is then tested is that the *n* plus and minus signs are sampled from a population in which the two kinds of signs are present in equal proportions (Sokal and Rohlf 1996). Only paired tows with at least one fish present in either net were included. The sign test was conducted on those species that were present in at least 10 tows.

Ratios of total weight of the major stocks of concern captured were calculated again haddock for the control and experimental nets individually. The stocks of concern included in the analysis were cod, yellowtail flounder, and winter flounder. In addition, the ratio of skate to haddock was calculated.

Length

An independent t-test was used to compare mean length between the control and experimental nets for each species measured (haddock, cod, yellowtail flounder, winter flounder, witch flounder, and American plaice). This test is used to compare two independent groups and determine if a significant different exists between the groups with respect to their mean scores (Hatcher 2003). SAS 9.1 was used to conduct the t-test and the hypothesis tested was:

H_0: the mean size in the control and experimental nets is the same, $\mu_1 = \mu_2$.

H_A: the mean size in the control and experimental nets is not the same, $\mu_1 \neq \mu_2$.

RESULTS

Weight

The total weight of all species captured was 56679.31 and 18600.07 kg in the control and experimental nets, respectively (Table 2). The control net caught 34 different species while the experimental net caught 29 (Figures 10 and 11). Separation of barndoor skate was not conducted for every tow; therefore some barndoor skate may have been included in the unclassified skate category. For the control net, more than 76% of the total catch was comprised of skate, haddock, and winter flounder which constituted 33.4%, 22.2%, and 20.8%, respectively. Haddock was the dominant species caught in the experimental net which comprised 77% of the total catch.

Total catch weights for key species broken down by trip and total for all trips can be found in Figures 12-14. Investigating seasonal differences for each net separately showed that greater than 50% of the haddock was caught in the June 2005 trip for both nets (7574.81 kg C and 8284.82 kg E) (Table 3). Cod catch was low in the first three trips with over 80% caught in the April 2006 trips in each net (3134.4 kg C and 614.21 kg E). For the control net, 91.34% (887.78 kg) of the yellowtail flounder was captured in June, November, and December 2005 with a similar quantity for each of those trips. The majority of yellowtail flounder was caught in the experimental net in December 2005 (67.26%, 63.88 kg). The majority of winter flounder was found in November 2005 for both nets. For the control net, 90.31% or 10658.27 kg was captured in November 2005. Winter flounder was 4% (748.55 kg) of the experimental total catch and 91.35% (683.81 kg) was captured in November 2005. Witch flounder and American plaice had the highest proportions in June 2005 consisting of greater than 60% of each nets catch. Skate catch was distributed fairly consistently throughout all trips, however, only 1.4% (257.71 kg) of the total catch in the experimental net was skate as compared to the 33.4% (18956.04 kg) of the control net. The majority of monkfish was caught in November 2005 with 78.2% (3553.04 kg) and 88.2% (214.67 kg) of total monkfish for the control and experimental nets, respectively. Other species catch weights for each trip can be found in Table 3.

The overall rounded ratio of haddock to cod from the control net was 3:1 which was improved in the experimental net to 20:1 (Figure 15). The ratio of haddock to yellowtail flounder was 13:1

and 151:1 for the control and experimental nets, respectively (Figure 15). The winter flounder ratio was 1:1 for the control net and 19:1 for the experimental net (Figure 16). For the control net, the number of skate was greater than the number of haddock with a 0.66:1 ratio whereas for the experimental net, the ratio was 56:1 (Figure 16).

There were 24 species that had fish present in at least 10 paired tows and the sign test was conducted on those species. Porbeagle shark (*Lamna nasus*) was found in 13 paired tows, however, exact weights were not taken and therefore they were not included in the analysis. The results of the sign test (Table 4) shows that the two nets did not differ in the weights of haddock, pollock (*Pollachius virens*), Atlantic herring (*Clupea harengus*), silver hake (*Merluccius bilinearis*), red hake (*Urophycis chuss*), illex squid (*Illex illecebrosus*), and loligo squid (*Loligo pealeii*). The control and experimental nets were not significantly different for these species, therefore fail to reject the null hypothesis. For cod, yellowtail flounder, winter flounder, witch flounder, American plaice and many other species, there was a significant difference in the catch weights between the control and the experimental nets (Table 4).

<u>Length</u>

Haddock, cod, and the majority of flatfish caught were measured for total length. The lengths of haddock ranged from 19-81 cm for the control net (*n*=5797) and 16-86 cm for the experimental net (*n*=6784) (Table 5). Cod lengths ranged from 17-97 cm (*n*=1212) and 45-94 cm (*n*=219) for the control and experimental nets, respectively (Table 5). The results of the t-test for lengths indicated no significant difference for all species but haddock. Results indicate that the control had a larger mean size of haddock; however, the mean lengths were 58.09 and 57.67 cm, for the control and experimental nets, respectively. The length-frequency graphs illustrate the length distributions observed in the control net and the experimental net via visual comparison (Figures 17 and 18).

DISCUSSION

The “Eliminator Trawl” successfully reduced the catch of the major stocks of concern. These included GB cod, GB yellowtail flounder, GB winter flounder, witch flounder, and American plaice. A variety of other species were also reduced such as skate and monkfish. In addition, haddock catch, the target species, was the same between the “Eliminator Trawl” and the currently regulated net.

The importance of reducing the catch of cod relates to the status of the stock which is overfished and experiencing overfishing (Mayo and Terceiro 2005). Due to the low level of cod, there is a zero bycatch tolerance which means that the haddock fishery is closed once the cod quota is reached. In 2004, the fishing industry lost over $15 million in haddock revenue due to the closing of the fishery (Table 1). The substantial reduction of cod in the “Eliminator Trawl” suggests that this net could be used as a tool to prevent the closure of the haddock fishery resulting in the utilization of the allotted TAC of haddock. In addition, the “Eliminator Trawl” virtually eliminated the catch of skates. The control caught 19000 kg which decreased to 260 kg in the experimental net, a reduction of 98.6%. This will become important as skates have the potential to be reclassified as overfished in the near future.

The results of this study may lead to the inclusion of the “Eliminator Trawl” in a B days-at-sea (DAS) program and a Special Access Program (SAP). Groundfish species are managed using a variety of methods, one method is DAS. The number of days vessels can use to harvest groundfish are limited. Amendment 13 to the NE Multispecies FMP defined three categories of DAS. The 2 main types are A DAS that can be used to target any regulated groundfish stock and B DAS that are used to target healthy groundfish stocks (stocks that are not overfished and that are not subject to overfishing). The usage of B DAS has been made possible through the Regular B DAS Program first established as a pilot program under Framework Adjustment 40A to the NE Multispecies FMP. Under the Final Rule for Framework 42 of NE Multispecies FMP this program is no longer a pilot program and will remain in effect indefinitely (50 CFR Part 648). This program allows vessels to utilize B DAS with a variety of specific conditions for their use. Trawl vessels participating in the Regular B DAS Program must use an approved haddock separator trawl. This restriction reduces the potential for vessels to catch stocks of concern, notably cod, yellowtail flounder, and winter flounder. Furthermore, possession of flounders (all species, combined); monkfish (whole weight); and skates is limited to 500 lb (227 kg) each, and possession of lobsters is prohibited.

The results of this study for the "Eliminator Trawl" fall within these guidelines. The net caught a total of 871.62 kg of flounders in 150 hours of towing (100 tows at 1.5 hours each) for an average of 5.81 kg per hour. For a 16 hour fishing day, that would amount to 92.97 kg per day. The total weight of skate and monkfish was 257.71 and 243.53 kg for 150 hours, for an average of less than 28 kg per 16 hour day for both species. Currently the haddock separator trawl is the only approved gear that can be used in the Regular B DAS Program. However, the Regional Administrator has authority to approve the use of additional gear for this program, based on approved gear standards recommended by the Council. The results of the study presented in this report demonstrate the effectiveness of the "Eliminator Trawl" to reduce the catch of all the stocks of concern encountered: Georges Bank cod, Georges Bank Yellowtail Flounder, Georges Bank winter flounder, witch flounder, American plaice, and white hake. This net certainly falls within the restrictions under the Regular B DAS Program and should be considered an alternative to the separator trawl.

The establishment of SAPs has been used as a method to provide fishermen access to healthier stocks by utilizing selective trawls that minimize the catch of stocks of concern. SAPs allow limited entry into closed areas with specific regulatory requirements. There are a few examples of SAPs that have been created. One program allows vessels using specially designed gear to fish in a portion of the Eastern U.S./Canada Area, including the northernmost tip of GB CA II. The Final Rule for Framework 42 renewed the Eastern U.S./Canada Haddock SAP Program and formalized it from a pilot program. The SAP program allows limited access for vessels fishing with an authorized haddock separator trawl to catch haddock using a Category B DAS (50 CFR Part 648). As with the Regular B DAS Program, the Regional Administrator has authority to approve the use of additional gear specifically for this SAP based on approved gear standards recommended by the Council. In order to limit the potential impact on fishing mortality that the use of Category B DAS may have on GB cod, Incidental Catch TACs for GB cod, as well as GB yellowtail flounder and GB winter flounder were established. Therefore, bycatch of these species should be at a minimum when participating in the SAP Program otherwise the vessel must exit the Program and flip to a Category A DAS. Trawl gear that limits the catches of those stocks of concern that would likely be caught in the SAP area is crucial to keeping programs like this going and/or being established. Data for the "Eliminator Trawl" suggests that this net would be an efficient tool as it appears to meet the minimum bycatch requirements to be seriously considered for a SAP for all of Georges Bank.

The impact of bottom trawls on the seabed has been one of the greatest criticisms of this type of gear. In recent years, researchers have begun to look at technological innovations that may reduce the impact on the seabed. In addition to the main opportunities the "Eliminator Trawl" may provide as discussed above, an unintended consequence of the utilization of this net is the reduction of bottom impact due to the design of the rockhopper sweep. The sweep was designed to allow demersal fish to escape through the 60 cm spacing between the large 16 inch discs located in its center; however, the reduction of the number of discs from five 16 inch discs between bights on the sweep of the currently regulated net to one 16 inch disc per bight at the center makes for a lighter sweep with less contact on the seabed.

The results for the "Eliminator Trawl" suggest some important possibilities for the fishing industry when trying to exploit healthy stocks while avoiding stocks of concern. The majority of fishing is conducted in a multispecies setting, therefore developing selective gear that can help protect stocks that need rebuilding is essential. The "Eliminator Trawl" did not reduce the catch of the target species, haddock, but did significantly decrease the catch of cod and other stocks of concern. Ten years ago, Hall (1996) stated challenges that the fishing industry would have to face in relation to bycatch. He suggested that 'the fishing industry will have to lead the way in the development of improved or alternative ways of fishing.' Collaborative research has evolved over the years to a process that is now frequently fishermen driven. This study is a good example of scientists, industry, and managers working together to develop more selective fishing gear.

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Table 1. Fishing data for haddock for three years including TAC, landings for each year, and the value lost by fishermen due to not reaching the TAC because the haddock fishery was closed. Fishing data obtained from the Fisheries Statistics Division of NOAA Fisheries online commercial fishery landings program. TAC info was obtained from the NOAA Fisheries Office of Sustainable Fisheries.

Year	TAC (mt)	Landings (mt)	Total value ($)	$/mt	TAC not harvested (mt)	Value lost ($)
2002	11,680	7540.9	19,047,274	2526.16	4139.1	10,456,028
2003	11,680	6777	16,946,210	2500.55	4903	12,260,196
2004	14,955	8242.1	18,529,339	2248.13	6712.9	15,091,471
						37,807,695

Table 2. Total catch weights and percentages for all trips combined. Weight is in kilograms. Note: porbeagle and mako shark weights were estimated

	CONTROL		EXPERIMENTAL	
	Total Weight	%	Total Weight	%
HADDOCK	12579.99	22.20	14327.02	77.03
COD	3768.90	6.65	703.12	3.78
YELLOWTAIL FLOUNDER	971.94	1.71	94.98	0.51
WINTER FLOUNDER	11802.36	20.82	748.55	4.02
WITCH FLOUNDER	104.38	0.18	7.42	0.04
AMERICAN PLAICE	522.83	0.92	4.46	0.02
WINDOWPANE FLOUNDER	182.08	0.32	9.19	0.05
WHITE HAKE	71.56	0.13	5.68	0.03
POLLOCK	52.80	0.09	85.74	0.46
ATLANTIC HALIBUT	5.70	0.01	1.28	0.01
OCEAN POUT	66.09	0.12	2.70	0.01
Total Regulated Groundfish	30128.62	53.16	15990.14	85.97
SUMMER FLOUNDER	43.85	0.08	5.74	0.03
FOURSPOT FLOUNDER	212.46	0.37		
MONKFISH	4543.30	8.02	243.53	1.31
ATLANTIC HERRING	47.91	0.08	68.60	0.37
BLUEFISH	7.50	0.01	11.90	0.06
CUNNER	2.14	0.00		
ATLANTIC MACKEREL	0.45	0.00	1.23	0.01
ATLANTIC WOLFFISH	48.28	0.09		
SILVER HAKE	39.62	0.07	29.83	0.16
RED HAKE	20.48	0.04	2.04	0.01
LONGHORN SCULPIN	112.23	0.20	8.01	0.04
SEA RAVEN	402.54	0.71	12.91	0.07
LUMPFISH	28.5	0.05	27.62	0.15
CUSKEEL UNCL	1.5	0.00		
SKATE UNCL	18525.89	32.69	241.63	1.30
SKATE BARNDOOR	430.15	0.76	16.08	0.09
Total Skate	18956.04	33.44	257.71	1.39
ATLANTIC TORPEDO RAY	20.7	0.04		
SPINY DOGFISH	957.46	1.69	158.93	0.85
PORBEAGLE SHARK	340	0.60	1640	8.82
SHORTFIN MAKO SHARK			50	0.27
AMERICAN LOBSTER	489.33	0.86	58.54	0.31
SEA SCALLOP LIVE	248.37	0.44	1.08	0.01
ILLEX SQUID	6.77	0.01	12.21	0.07
LOLIGO SQUID	20.04	0.04	20.05	0.11
JONAH CRAB UNSEXED	1.22	0.00		
Total	56679.31	100.00	18600.07	100.00

Table 3. Weight in kilograms for each species sampled separated into trips and total weight for all trips combined. Note: porbeagle and mako shark weights were estimated.

		June 2005		November 2005		December 2005		April 2006		TOTAL	
		C	E	C	E	C	E	C	E	C	E
Regulated Groundfish	HADDOCK	7574.81	8284.82	2583.79	2899.45	728.44	925.79	1692.95	2216.96	12579.99	14327.02
	COD	377.46	60.62	121.33	13.50	135.71	14.79	3134.40	614.21	3768.90	703.12
	YELLOWTAIL FLOUNDER	248.92	10.74	254.12	19.44	384.74	63.88	84.16	0.92	971.94	94.98
	WINTER FLOUNDER	15.18	0	10658.27	683.81	1031.99	64.74	96.92	0	11802.36	748.55
	WITCH FLOUNDER	93.73	7.02	0.60	0.40	0.14	0	9.91	0	104.38	7.42
	AMERICAN PLAICE	337.38	3.38	0	0	5.90	0	179.55	1.08	522.83	4.46
	WINDOWPANE FLOUNDER	0	0	4.43	0.82	15.76	2.31	161.89	6.06	182.08	9.19
	WHITE HAKE	21.00	0	35.04	2.10	15.52	3.58	0	0	71.56	5.68
	POLLOCK	4.42	10.50	0	7.36	17.80	65.82	30.58	2.06	52.80	85.74
	SUMMER FLOUNDER	10.94	0	0	0	0	0	32.91	5.74	43.85	5.74
	FOURSPOT FLOUNDER	36.72	0	143.09	0	32.65	0	0	0	212.46	0
	ATLANTIC HALIBUT	0	0	0	0	1.66	1.28	4.04	0	5.70	1.28
	MONKFISH	573.13	21.10	3553.04	214.67	234.99	7.76	182.14	0	4543.30	243.53
	ATLANTIC HERRING	31.96	16.90	13.59	46.98	1.50	4.72	0.86	0	47.91	68.60
	BLUEFISH	0	0	7.50	11.90	0	0	0	0	7.50	11.90
	CUNNER	1.34	0	0.54	0	0.26	0	0	0	2.14	0
	ATLANTIC MACKEREL	0.10	0	0.05	0.14	0.30	1.09	0	0	0.45	1.23
	ATLANTIC WOLFFISH	48.28	0	0	0	0	0	0	0	48.28	0
	SILVER HAKE	1.06	0.12	36.60	27.32	1.96	2.39	0	0	39.62	29.83
	RED HAKE	2.38	0.60	18.10	1.12	0	0.32	0	0	20.48	2.04
	LONGHORN SCULPIN	23.78	2.74	17.34	3.32	14.14	0.35	56.97	1.60	112.23	8.01
	OCEAN POUT	23.91	2.70	4.36	0	0.78	0	37.04	0	66.09	2.70
	SEA RAVEN	113.06	0	21.66	0	36.58	0.78	231.24	12.13	402.54	12.91
	LUMPFISH	0	0	0	0	2.78	0	25.72	27.62	28.50	27.62
	CUSKEEL UNCL	0	0	0	0	1.50	0	0	0	1.50	0
	SKATE	4735.73	97.64	5859.72	55.02	3599.32	76.68	4761.27	28.37	18956.04	257.71
	ATLANTIC TORPEDO RAY	0	0	20.70	0	0	0	0	0	20.70	0
	SPINY DOGFISH	12.56	0	6.47	0	687.79	108.44	250.64	50.49	957.46	158.93
	PORBEAGLE SHARK	340	1490	0	0	0	150	0	0	340	1640
	SHORTFIN MAKO SHARK	0	50	0	0	0	0	0	0	0	50
	AMERICAN LOBSTER	235.86	39.34	81.46	10.26	170.57	8.94	1.44	0	489.33	58.54
	SEA SCALLOP LIVE	96.94	0	103.71	1.08	47.12	0	0.60	0	248.37	1.08
	ILLEX SQUID	2.80	3.32	3.59	7.54	0.38	1.35	0	0	6.77	12.21
	LOLIGO SQUID	0	0	16.26	19.02	3.78	0.85	0	0.18	20.04	20.05
	JONAH CRAB	0	0	0.38	0	0.84	0	0	0	1.22	0
	TOTAL	14963.447	10101.54	23565.74	4025.25	7174.897	1505.86	10975.226	2967.42	56679.31	18600.07

Table 4. Results from the nonparametric paired comparison of weights. The *P*-value is from the sign test. Those species highlighted in grey resulted in no significant difference between the control and experimental nets.

Species	*P*-value	*n*
HADDOCK	1.000	97
COD	<.0001	85
YELLOWTAIL FLOUNDER	<.0001	91
WINTER FLOUNDER	<.0001	64
WITCH FLOUNDER	<.0001	35
AMERICAN PLAICE	<.0001	65
WINDOWPANE FLOUNDER	<.0001	56
WHITE HAKE	0.0007	19
POLLOCK	0.5811	13
SUMMER FLOUNDER	<.0001	18
FOURSPOT FLOUNDER	<.0001	51
ATLANTIC HALIBUT	-	-
MONKFISH	<.0001	78
ATLANTIC HERRING	0.7608	45
BLUEFISH	-	-
CUNNER	-	-
ATLANTIC MACKEREL	-	-
ATLANTIC WOLFFISH	-	-
SILVER HAKE	0.2005	30
RED HAKE	0.0574	14
LONGHORN SCULPIN	<.0001	74
OCEAN POUT	<.0001	32
SEA RAVEN	<.0001	76
LUMPFISH	-	-
CUSKEEL UNCL	-	-
SKATE	<.0001	99
TORPEDO RAY ATLANTIC	-	-
SPINY DOGFISH	<.0001	37
PORBEAGLE SHARK	-	-
SHORTFIN MAKO SHARK	-	-
AMERICAN LOBSTER	<.0001	56
SEA SCALLOP LIVE	<.0001	51
ILLEX SQUID	0.3771	32
LOLIGO SQUID	0.7201	31
JONAH CRAB	-	-

Table 5. Length data in cm for those species measured including range, number measured (*n*), and mean length.

	Control			Experimental		
Species	Range	*n*	Mean Length	Range	*n*	Mean Length
Haddock	19-81	5797	58.09	16-86	6784	57.67
Cod	17-97	1212	68.22	45-94	219	69.10
Yellowtail Flounder	22-52	1278	40.82	26-52	130	42.06
Winter Flounder	25-63	7335	48.38	27-61	446	48.29
Witch Flounder	26-56	156	45.00	43-53	4	46.25
American Plaice	15-64	726	40.51	33-53	5	42.80

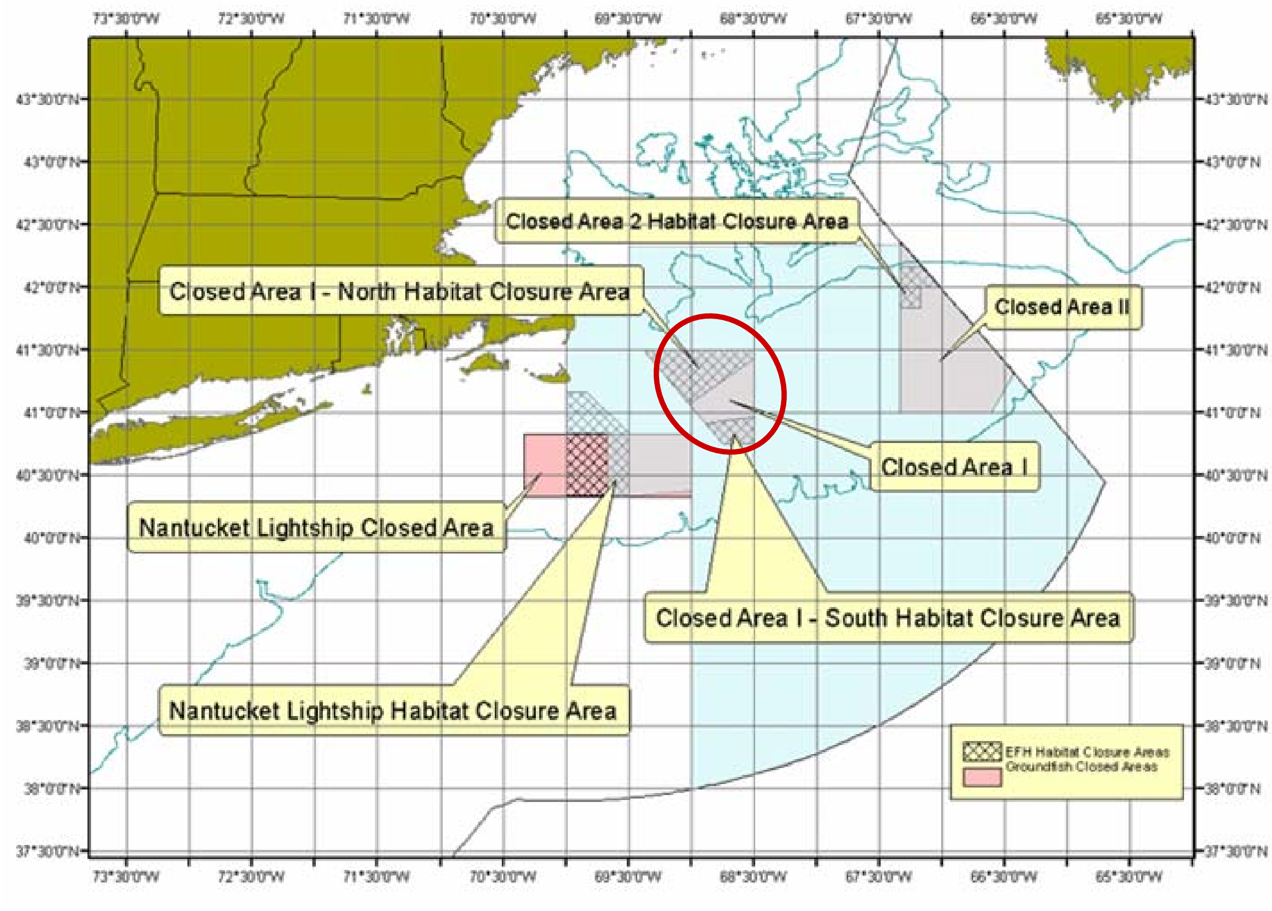


Figure 1. Map showing closed areas including the study area, CA I, circled in red. Sampling was conducted in the area between the north and south habitat closure areas.

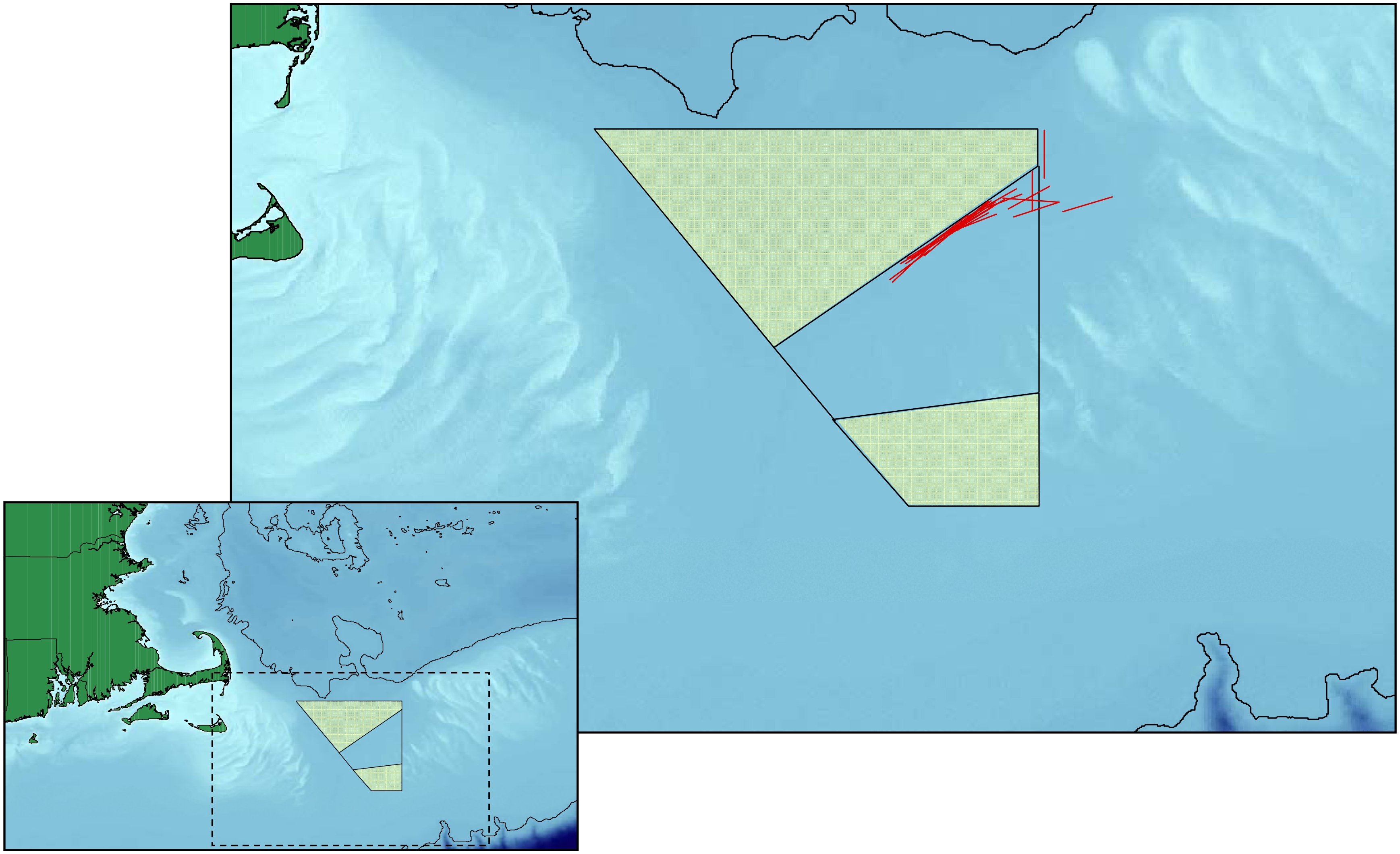


Figure 2. Trawling distribution map of tows (shown in red) conducted in June 2005 (29 tows). Lines correspond to the beginning and ending coordinates of each tow. Areas shown in yellow are the North and South Habitat Closure Areas. Note: for simplification, only one vessel is included on the map.

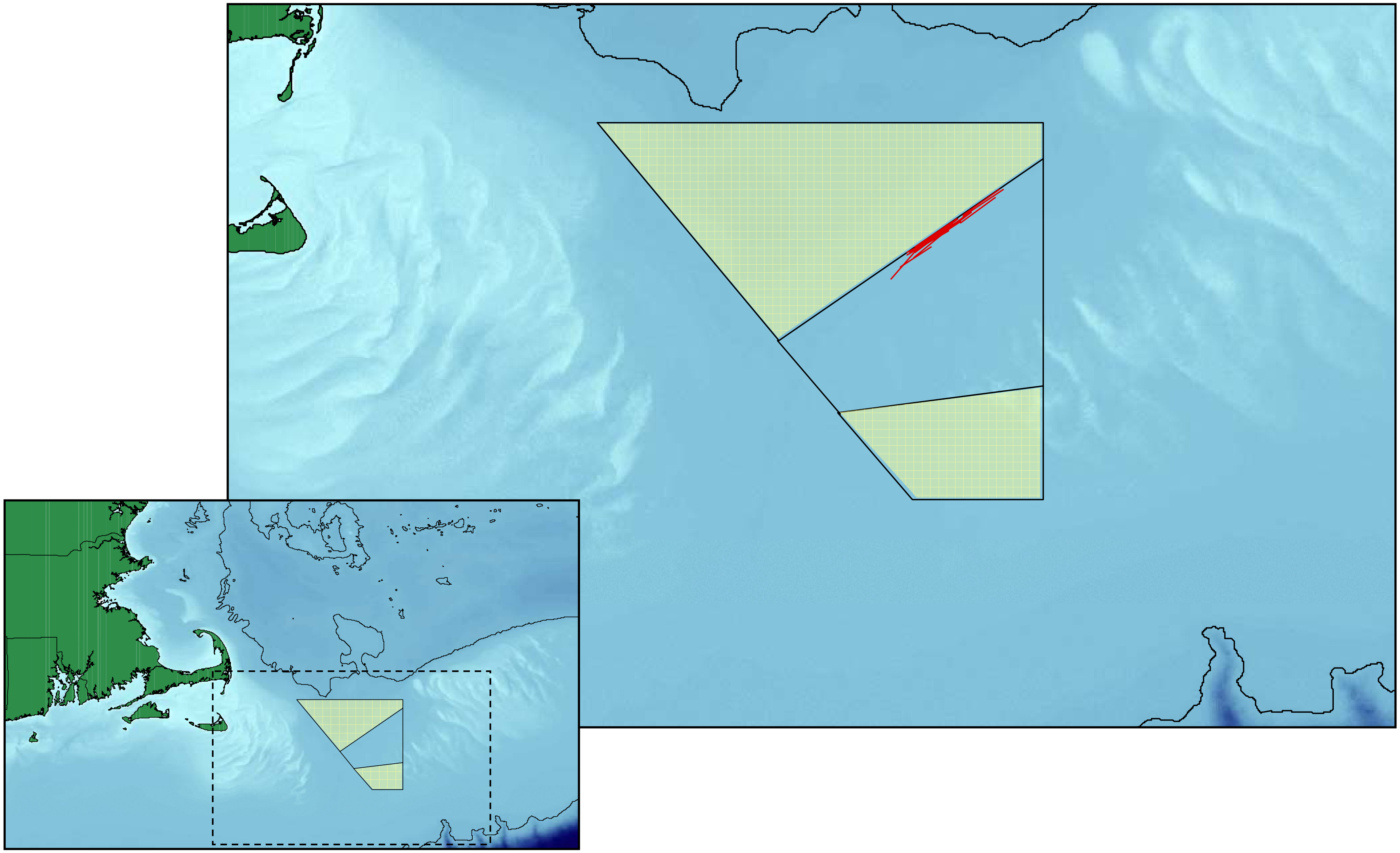


Figure 3. Trawling distribution map of tows (shown in red) conducted in November 2005 (23 tows). Lines correspond to the beginning and ending coordinates of each tow. Areas shown in yellow are the North and South Habitat Closure Areas. Note: for simplification, only one vessel is included on the map.

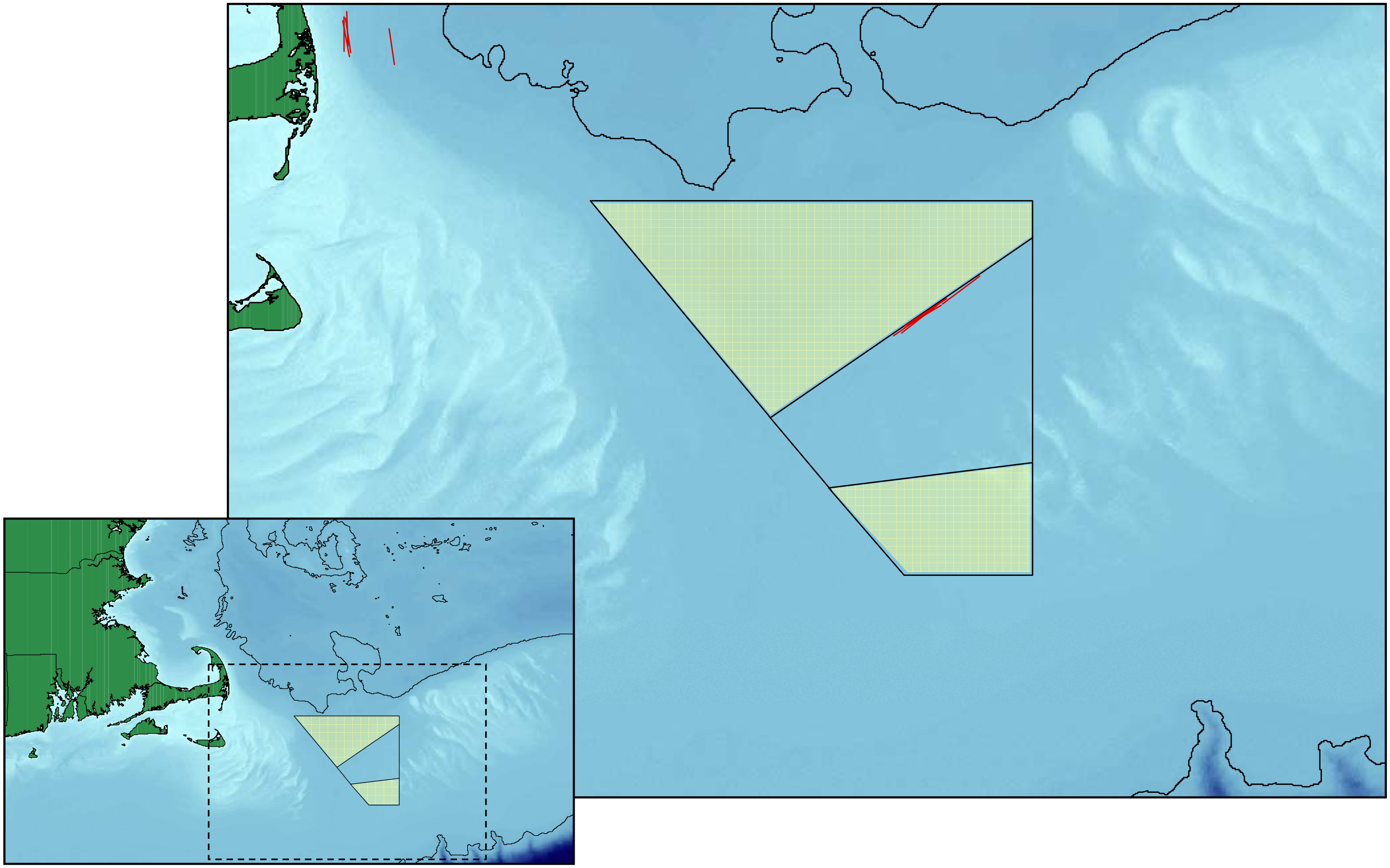


Figure 4. Trawling distribution map of tows (shown in red) conducted in December 2005 (11 tows). Lines correspond to the beginning and ending coordinates of each tow. Areas shown in yellow are the North and South Habitat Closure Areas. Note: for simplification, only one vessel is included on the map.

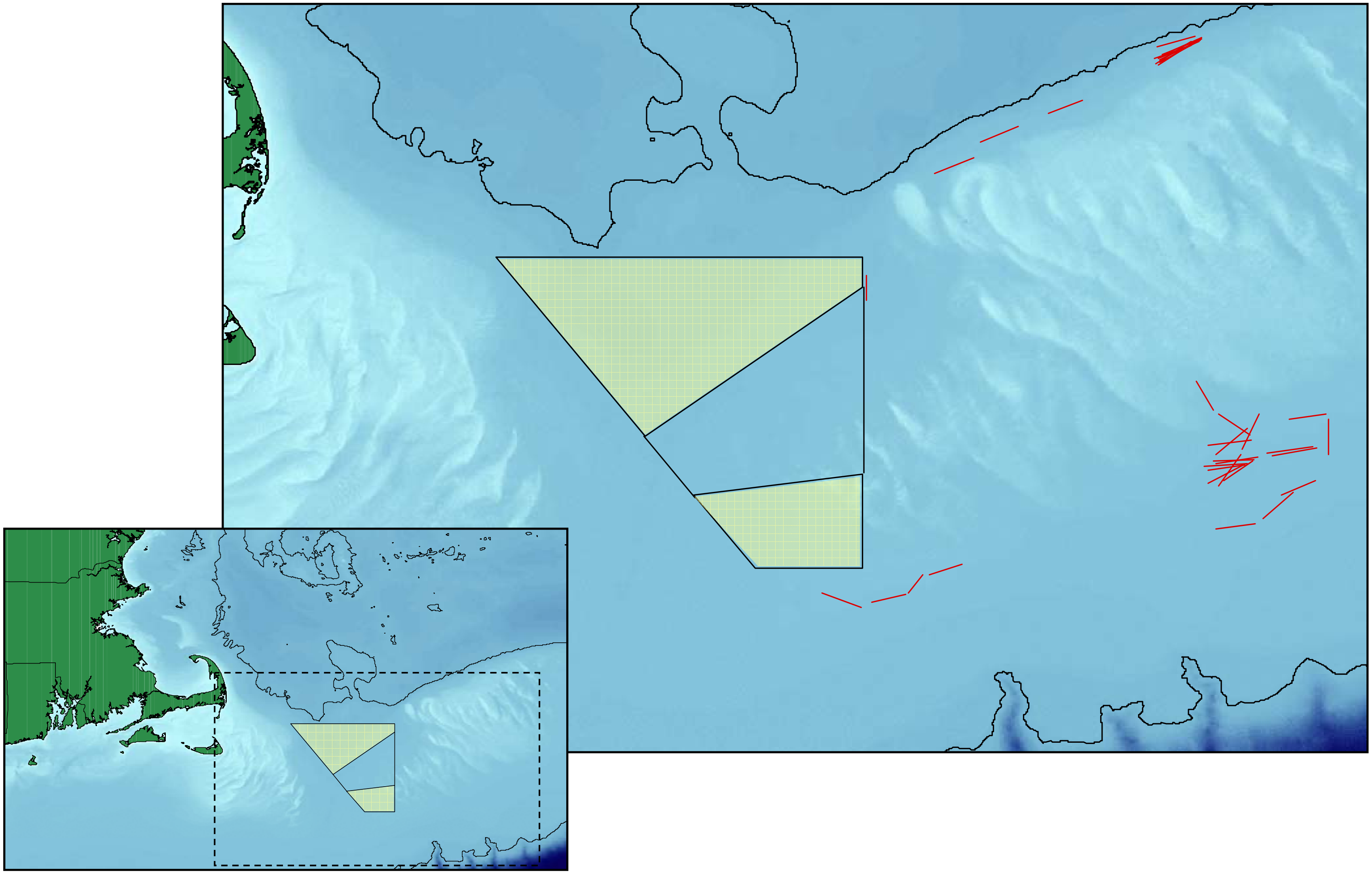


Figure 5. Trawling distribution map of tows (shown in red) conducted in April 2006 (37 tows). Lines correspond to the beginning and ending coordinates of each tow. Areas shown in yellow are the North and South Habitat Closure Areas. Note: for simplification, only one vessel is included on the map.

Figure 6. Photo of the rockhopper sweep of the control net showing the five 16 inch rubber discs per bight in the center.

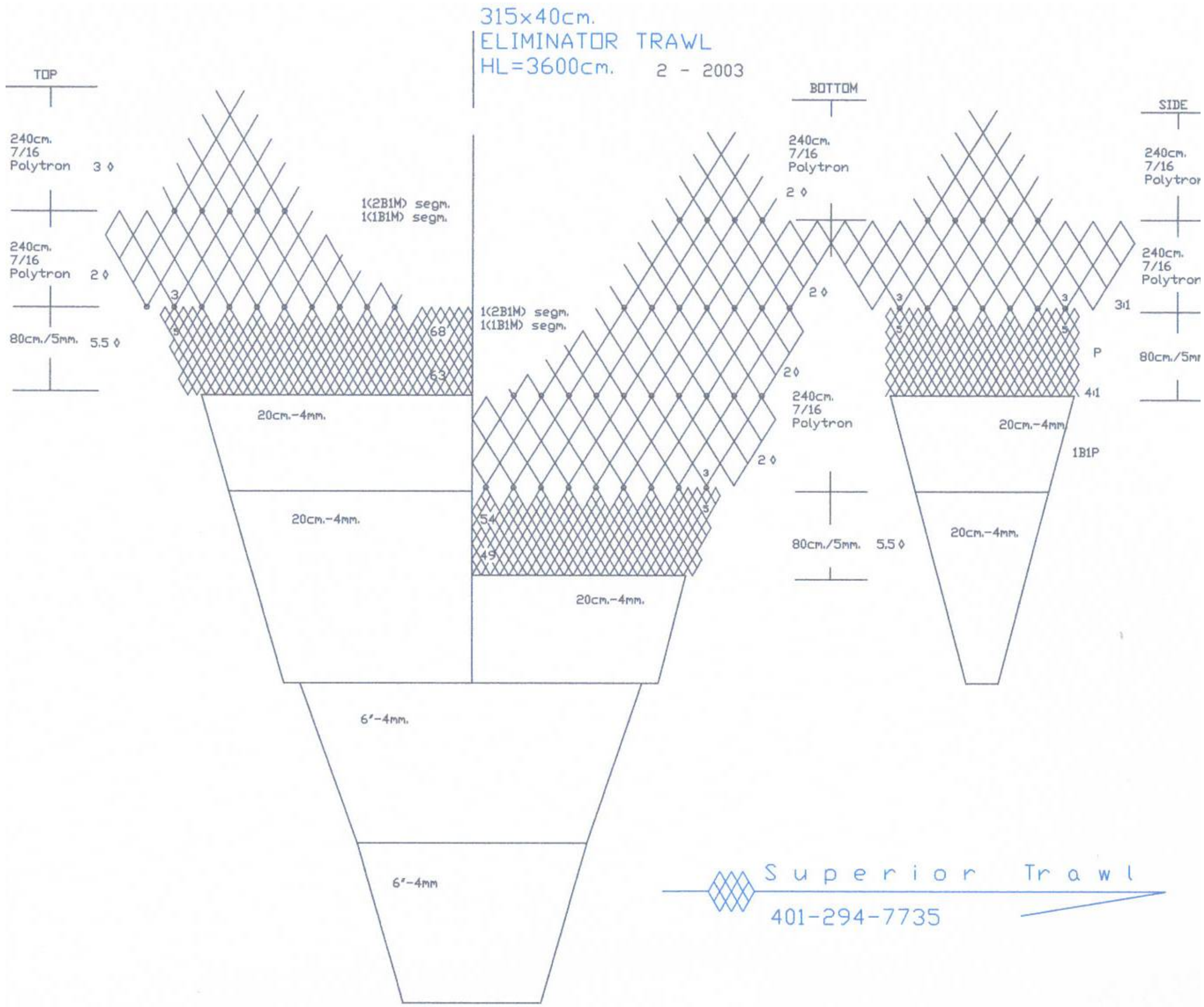


Figure 7. Net plan for the experimental net, the "Eliminator Trawl."

(a)

(b)

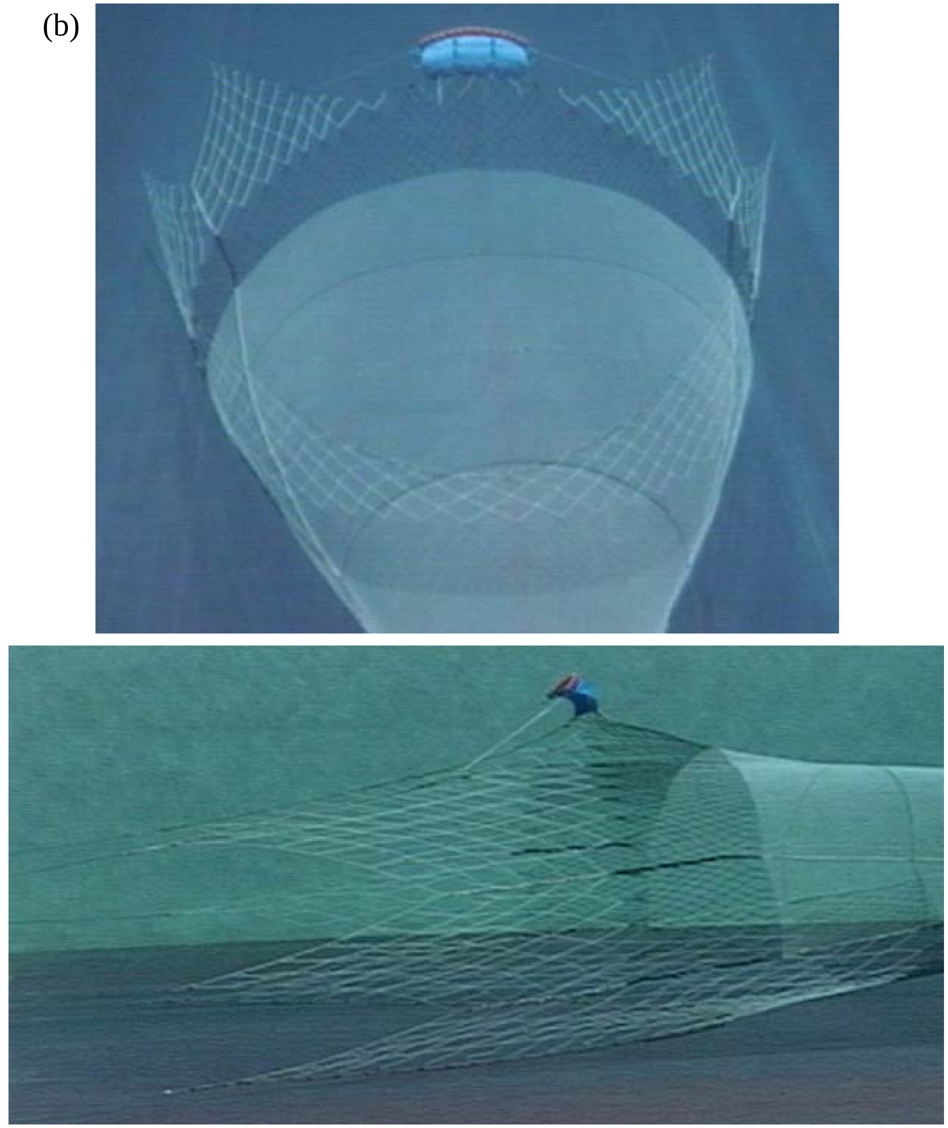


Figure 8. Photos of the experimental net, the “Eliminator Trawl”: (a) the large mesh at the mouth of the net and (b) model in the flume tank at the Marine Institute of Memorial University of Newfoundland – Centre for Sustainable Aquatic Resources.

Figure 9. Photo of the rockhopper sweep of the experimental net, the “Eliminator Trawl,” showing the one 16 inch disc per bight in the center.

Figure 10.Photos of the catch from the control net, the currently regulated trawl.

Figure 11. Photos of the catch from the experimental net, the “Eliminator Trawl.”

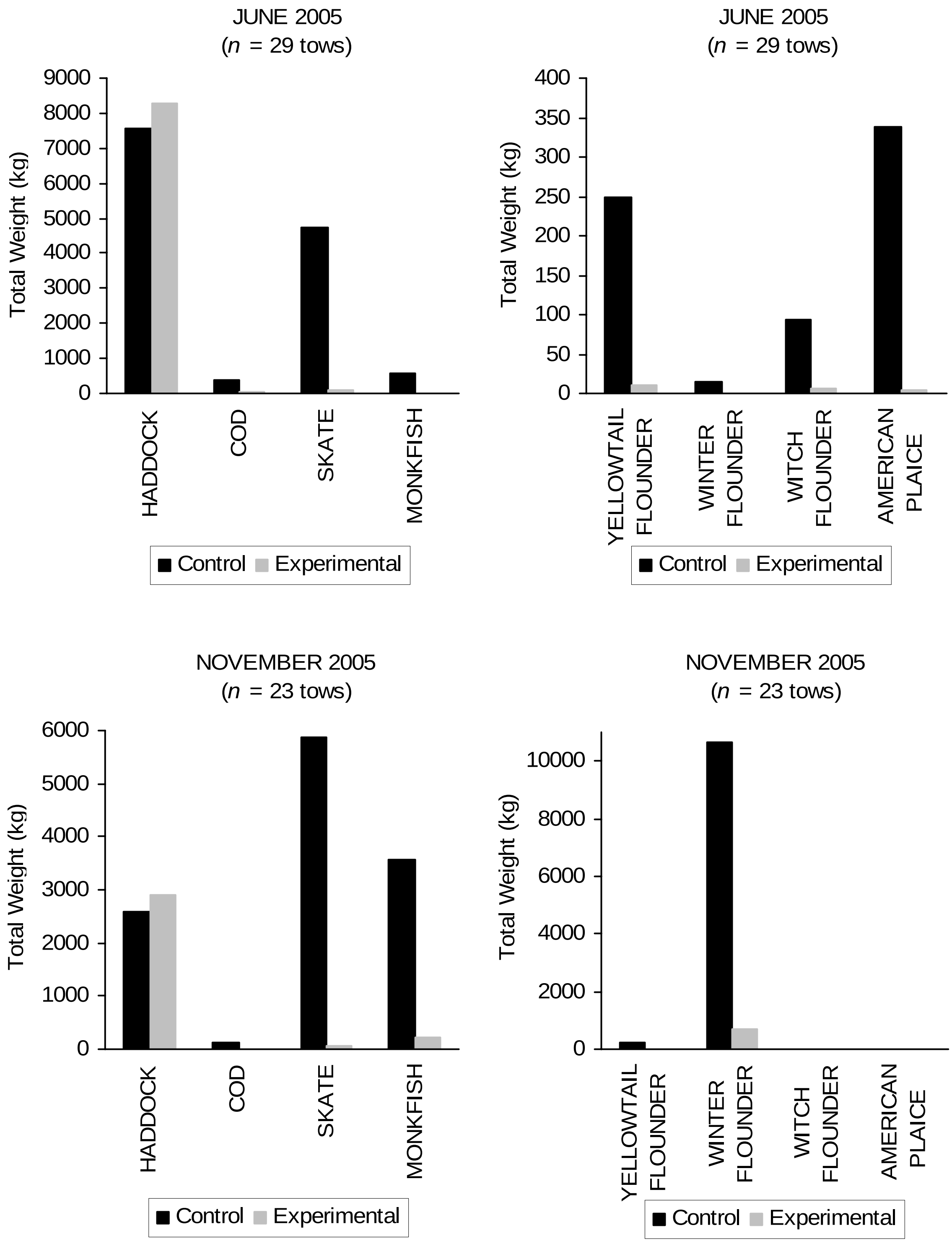


Figure 12.Total catch weight of key species for the June and November 2005 trips. Refer to Table 3 for exact weights. Note: scale of axis's for each graph is different.

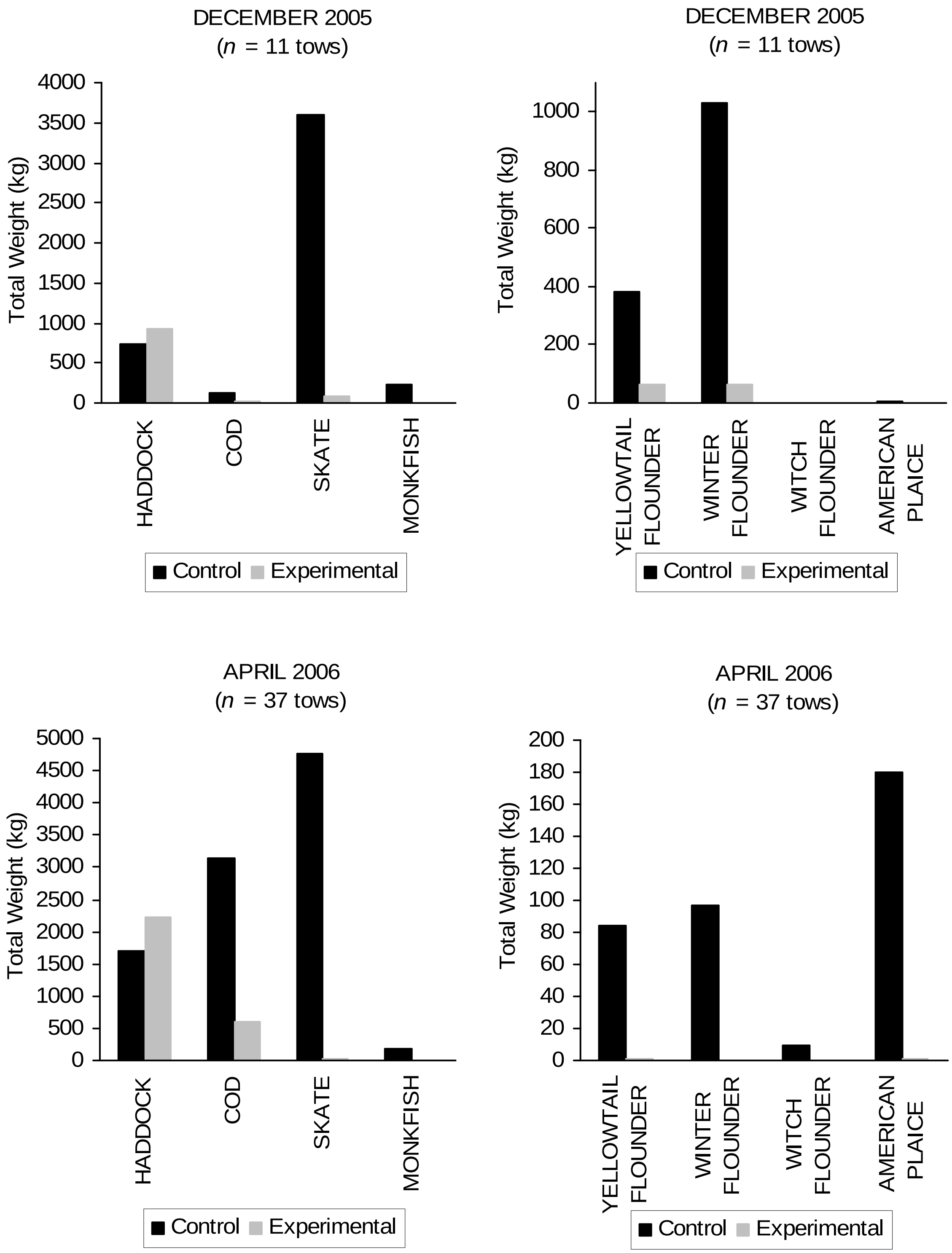
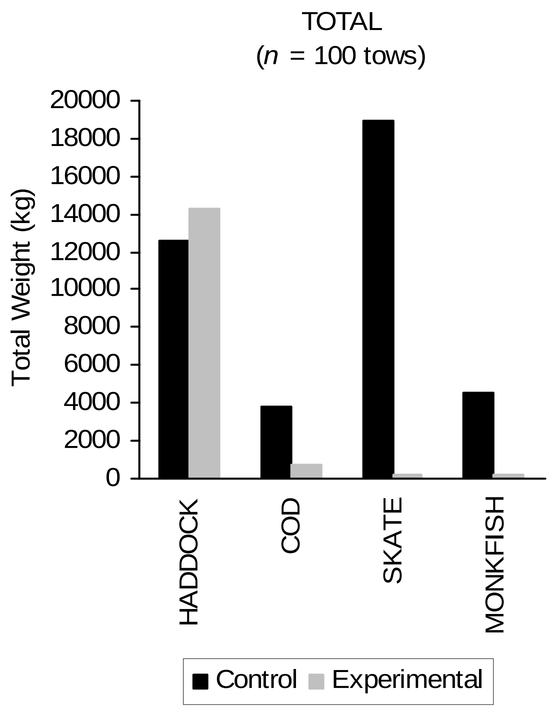


Figure 13.Total catch weight of key species for the December 2005 and April 2006 trips. Refer to Table 3 for exact weights. Note: scale of axis's for each graph is different.



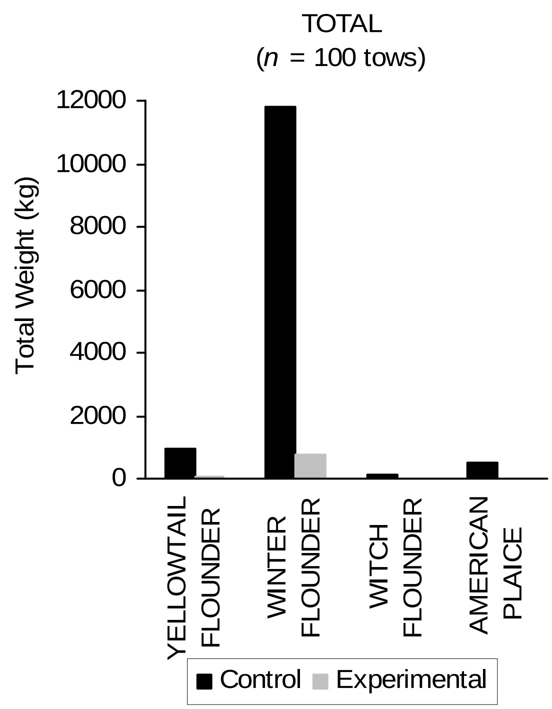


Figure 14.Total catch weight of key species for all trips combined. Refer to Table 3 for exact weights. Note: scale of axis's for each graph is different.

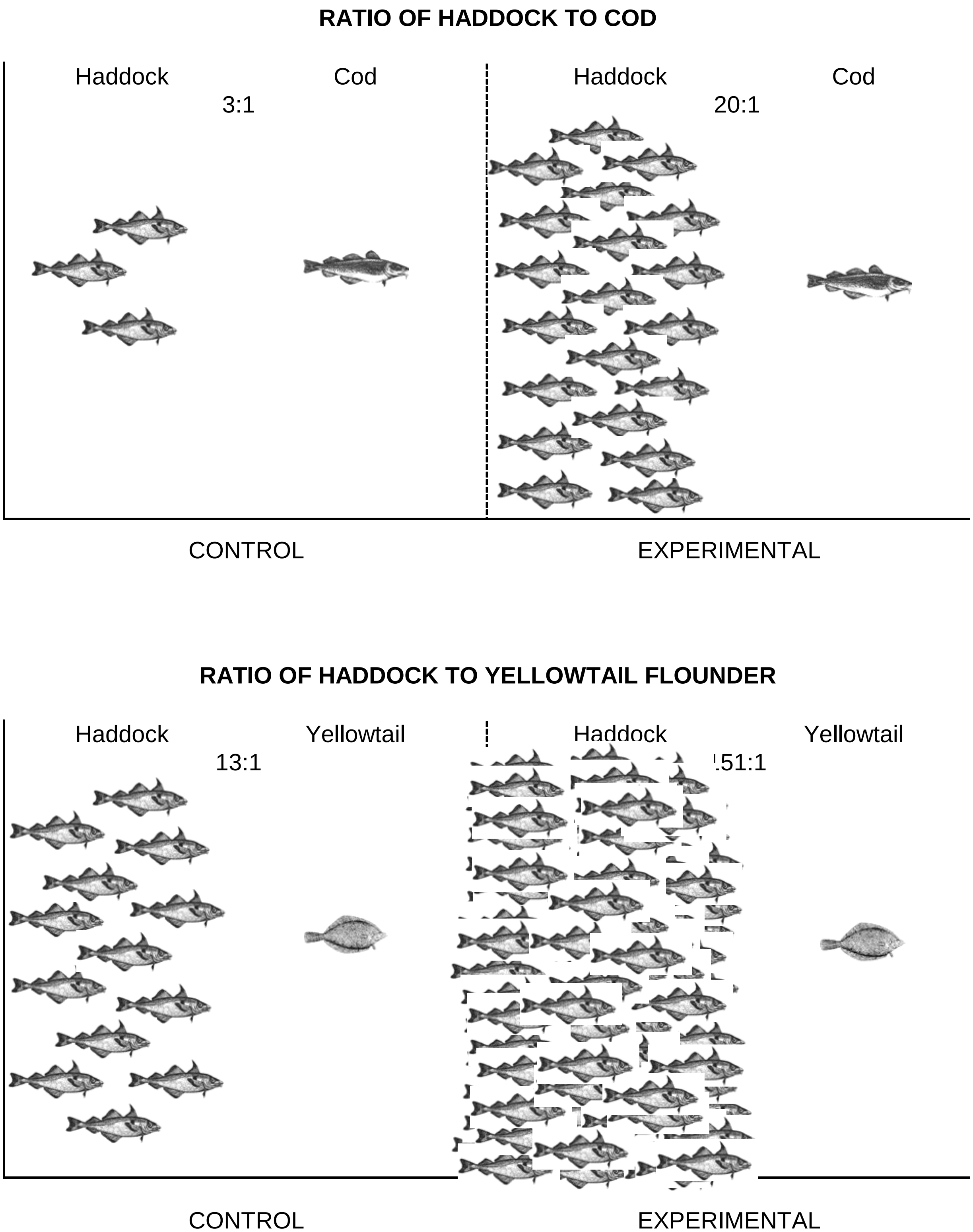
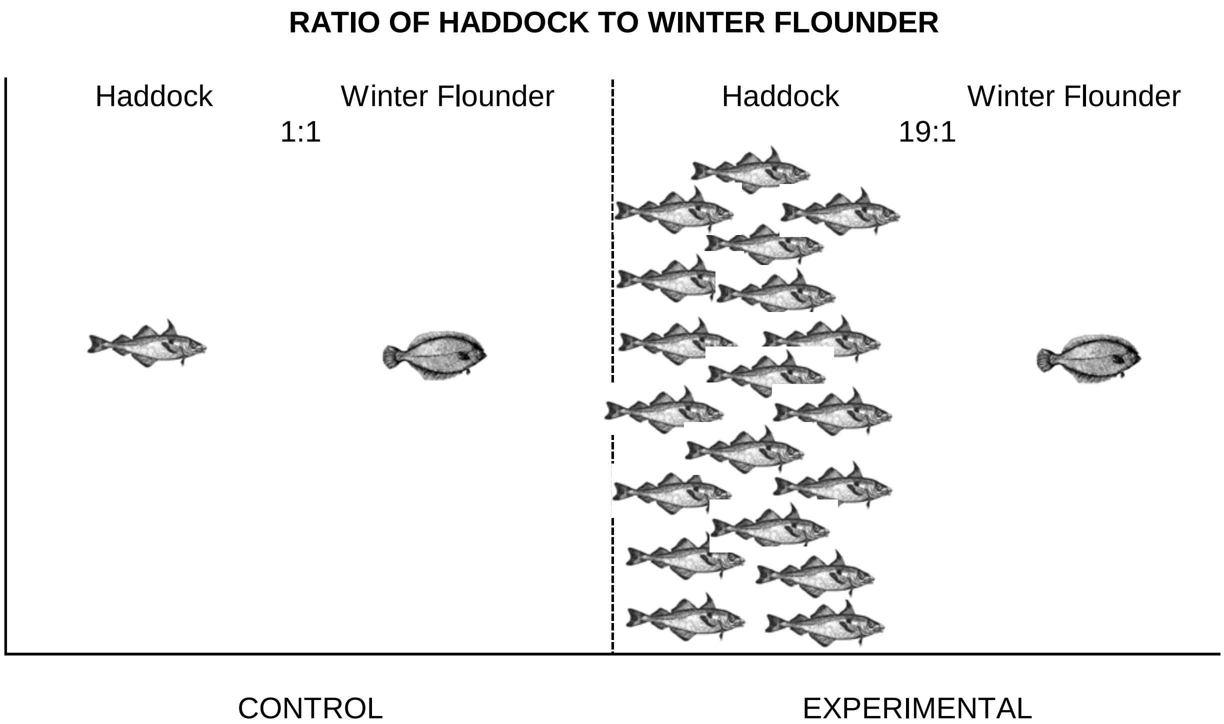


Figure 15. Visual representation of ratios of haddock to cod and yellowtail flounder.



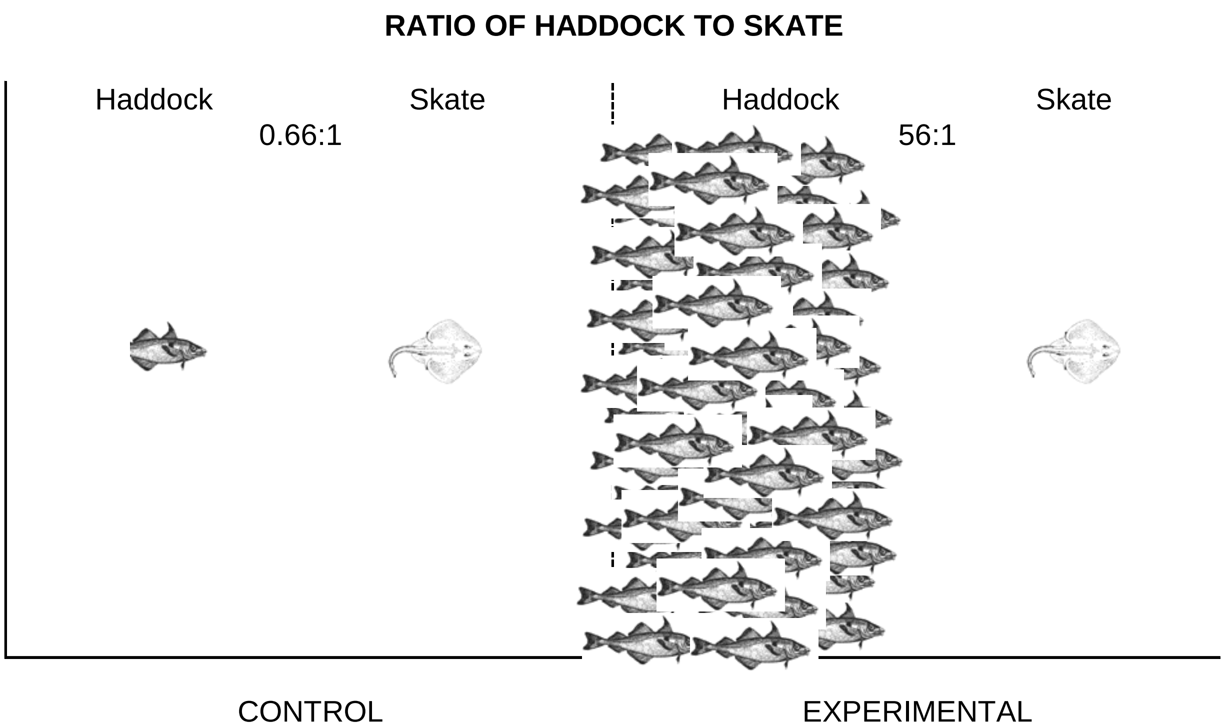


Figure 16. Visual representation of ratios of haddock to winter flounder and skate.

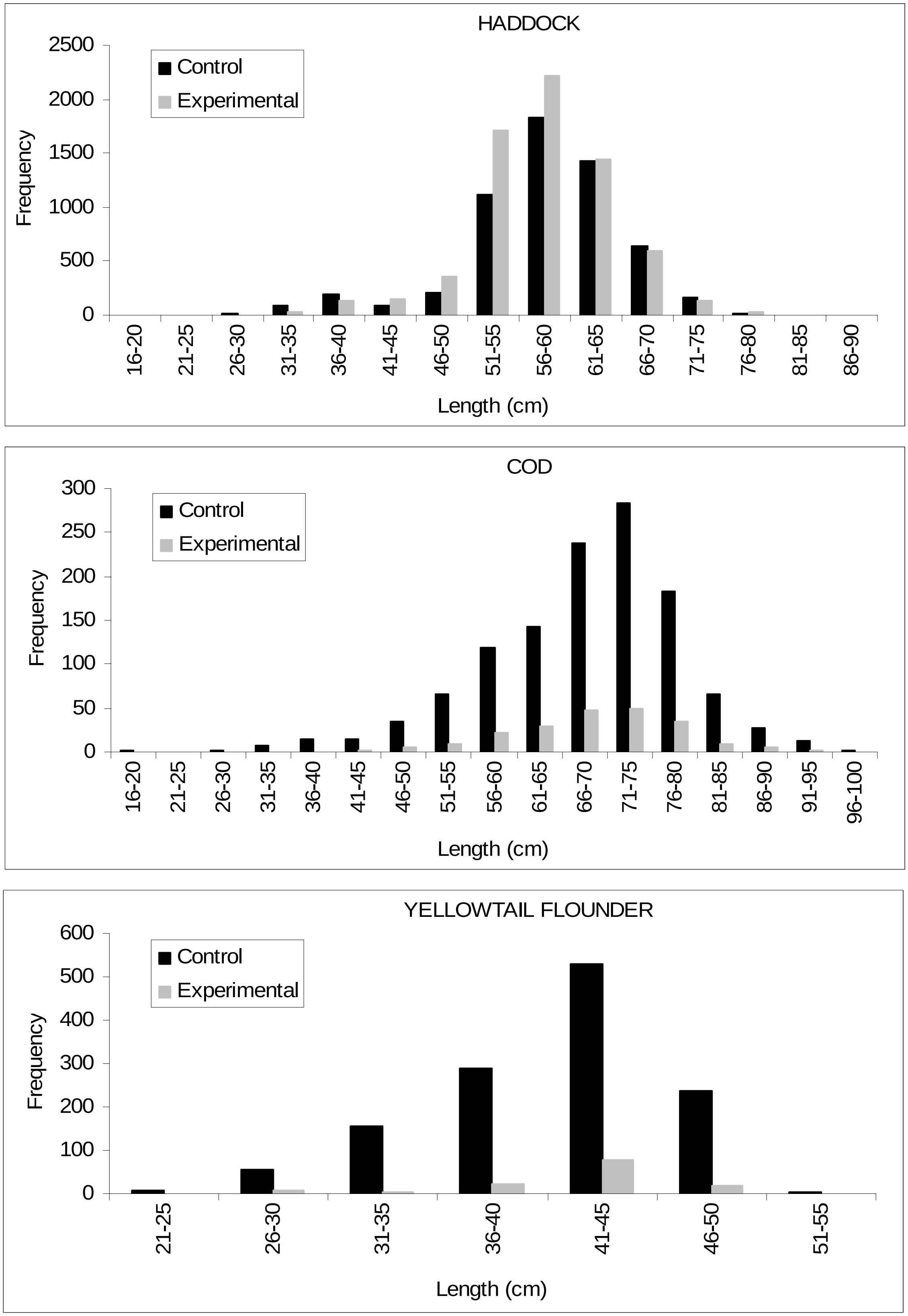


Figure 17. Length frequency for haddock, cod, and yellowtail flounder.

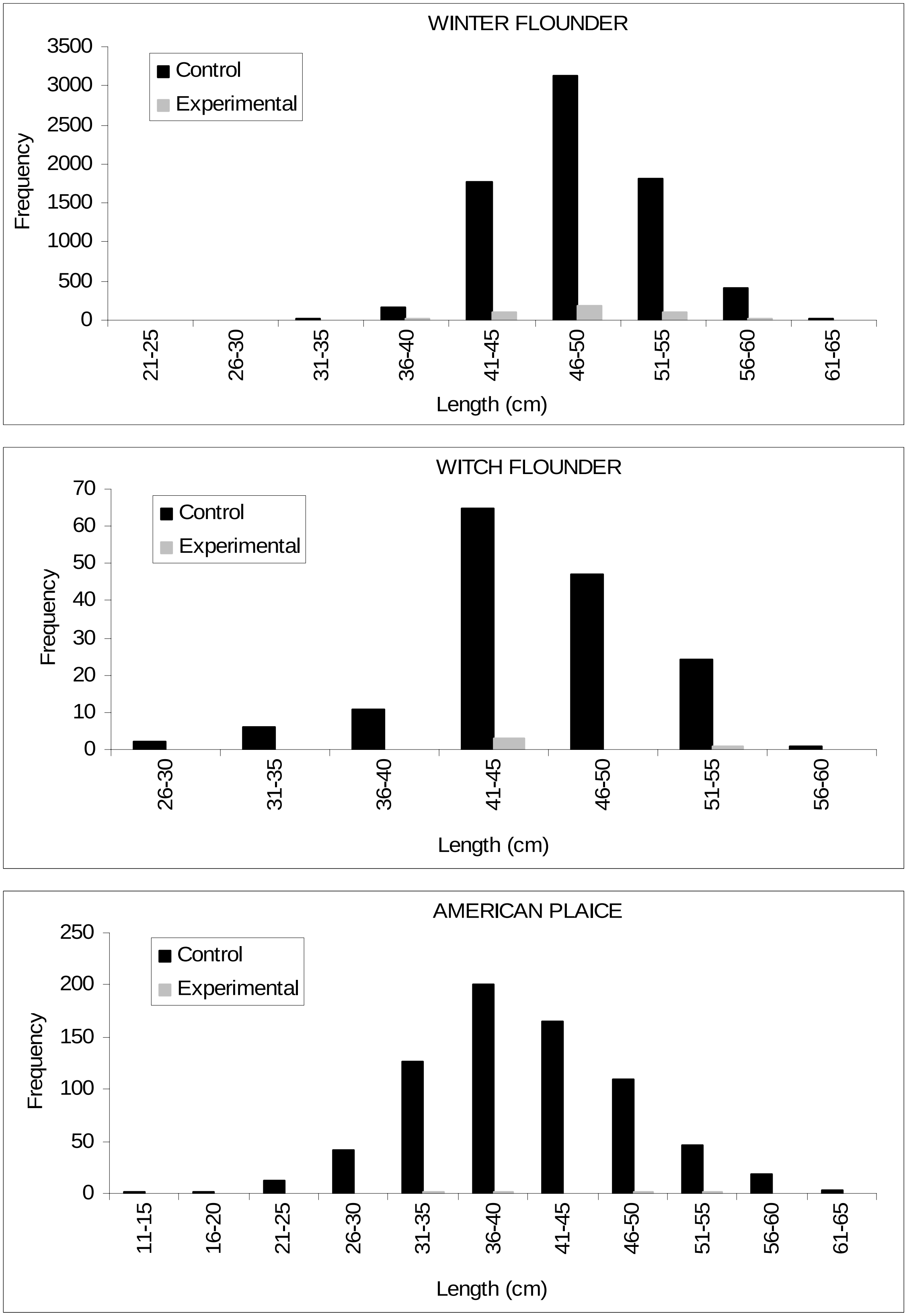


Figure 18. Length frequency for winter flounder, witch flounder, and American plaice.