Discards of commercial fish species in the Gulf of Maine groundfish and shrimp fisheries

Richard Langan
University of New Hampshire, Durham

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Discards of commercial fish species in the Gulf of Maine
groundfish and shrimp fisheries

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DISCARDS OF COMMERCIAL FISH SPECIES IN THE GULF OF MAINE GROUND FISH AND SHRIMP FISHERIES

by

Richard Langan

B.A. (Biology), Lehigh University, 1971
M.S. (Zoology), University of New Hampshire, 1980

Dissertation

Submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Zoology

May, 1992
This Dissertation has been examined and approved.

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April 18, 1992

Date
The idea for the research that resulted in this dissertation came about in 1982, while I was a first mate on a commercial trawler, fishing the inshore and offshore waters of the Gulf of Maine, from Portsmouth, New Hampshire. Unlike the trawl fisheries based in Southern New England and on Georges Bank, which were targeted toward a particular species such as yellowtail flounder or haddock, the vessel on which I fished from 1980-1982, the F/V Scotsman,, like many Gulf of Maine trawlers in the same size class ( 50'-80'), sought a mixed species catch. The composition of the catch varied depending upon season and area fished, but was generally about 50% flounders (4 species), and the remainder composed of varying amounts of cod, haddock, pollock, cusk, hakes, redfish, monkfish, and ocean catfish. It was also not unusual to catch substantial quantities of sea scallops on certain fishing grounds, and large numbers lobsters at certain times of the year. The species diversity and seasonal variation of the catch made by the Gulf of Maine fleet made the job of fisheries managers far more difficult than for a species directed fishery. The primary management tools at that time were closed spawning areas (primarily on Georges Bank), and vessel catch quotas for haddock, yellowtail flounder, and cod. Minimum fish size for cod, haddock, and yellowtail flounder and mesh size regulations also appeared at this time
(13.03 cm), however, they were not strictly enforced, and cheating was common. In addition, there were exemptions for vessels seeking to catch whiting, shrimp and redfish. These vessels were permitted to fish with small mesh provided the bycatch of groundfish did not exceed a predetermined percentage of the total catch.

This time period (1980-1982) also marked the beginning of a decline in groundfish landings that would accelerate at an alarming rate right up to the present time. Fishing effort increased dramatically and catch per unit effort decreased. Although these statistics were unavailable to me at the time, I was aware that catches were decreasing and that we (on our vessel), were discarding large numbers of fish, especially undersized flounders, during our normal groundfishing operations. The few trips we made in winter for shrimp produced far greater numbers and smaller sized discards. Realizing that discards could be a significant problem, I went to speak with Dr. Hunt Howell, who was recently hired at UNH as an Assistant Professor of Zoology, specializing in fisheries science and the early life history of flounders. Hunt agreed that this indeed could be a significant problem and encouraged me to pursue the idea. Hunt provided me with several contacts at the NMFS, Northeast Fisheries Center in Woods Hole, Massachusetts. Discussions with Steve Clark, Mike Sissenwine, and others at Woods Hole, indicated that federal fisheries scientists believed that discarding could potentially have a serious effect on biomass, recruitment and stock density, and that very little
discard data was available for the Gulf of Maine trawl fisheries. Dr. Howell and I were encouraged to develop a proposal to quantify discarding. After several versions of this proposal and an unsuccessful submission to NMFS, a modest proposal was funded by ME/NH Sea Grant Development. The project was conducted while I was first mate on the commercial trawler F/V Captain Gould, and I therefore had access to discard information from every tow made by that vessel for a five month period. Results of this project are reported in Part 1 of this dissertation. Two fishing trips for northern shrimp in the first study indicated that discarding was far worse in the shrimp fishery. Because of the preliminary shrimp fishery data from the first study, a second proposal, again funded by Sea Grant, focused on the Northern Shrimp fishery. The results of the shrimp fishery discard study are reported in Part 2 of this dissertation.

Due in part to data generated in these two studies, discarding has become widely recognized as one of the most significant issues in fisheries management. Fisheries scientists and gear specialists began serious work on trawl modifications intended to reduce bycatch and discards in the mid 1980's. Gear modifications and bycatch studies continue today, accompanied by changes in management schemes and federal fishery regulations. These developments are discussed in Part 3, "Gear Modifications and Regulations Associated with Bycatch and Discards in Trawl Fisheries."
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DISCARDS OF COMMERCIAL FISH SPECIES IN THE GULF OF MAINE GROUNDFISH AND SHRIMP FISHERIES

by

Richard Langan
University of New Hampshire, May, 1992

A three part analysis of discarding of commercial fish species in the Gulf of Maine trawl fisheries was conducted from 1983 through 1992. Abstracts for each part of the dissertation are:

Part 1.

The objectives of the research were to quantify commercial trawler discards of American plaice, witch flounder, yellowtail flounder, and winter flounder, and to examine variables that potentially influence discard rates. Data were obtained from 135 tows in 6 areas of the Gulf of Maine. Four different types of trawls were used. Mean discard percentages per tow, on a weight basis, were 25, 18, 13, and 5% for American plaice, witch flounder, yellowtail flounder, and winter flounder, respectively. Mean discard percentages were higher on a numerical basis, with 57, 27, 25, and 12% of the respective species discarded per tow. Both trawl type and area fished affected the discard percentages of American plaice and witch flounder. Stepwise multiple regression analyses indicated that six variables combined to explain 66.8% of the variation in discard percentage of American plaice, and that three variables combined to
explain 31.2% of the variation in discard percentage of witch flounder.

Part 2.

The objective of the research was to quantify discards of American plaice, witch flounder, yellowtail flounder, winter flounder, goosefish, silver hake, and cod in the Gulf of Maine shrimp fishery. Data were obtained from 50 tows made by commercial trawlers fishing in the southwestern Gulf of Maine. Mean discard percentages per tow, on a weight basis, were: 93% for silver hake, 87% for American plaice, 76% for witch flounder, 56% for cod, 41% for goosefish, 20% for yellowtail flounder, and 11% for winter flounder. Mean discard percentages per tow on a numerical basis were slightly higher. Discard percentage decreased with increasing depth for American plaice.

Part 3.

Increased effort in the Northern shrimp fishery, in addition to documentation of the adverse effects of small mesh trawls on some finfish stocks, has prompted interest the development of more selective fishing gear. Studies of fish behavior during the trawling process using underwater video have provided information that has been extremely useful for the design of selective trawls. In this paper, fish behavior, trawl modifications, particularly those intended to separate finfish from shrimp, and regulations aimed at reducing finfish bycatch are discussed.
PART 1. COMMERCIAL TRAWLER DISCARDS OF FOUR FLOUNDER SPECIES IN THE GULF OF MAINE
ABSTRACT

The objectives of the research were to quantify commercial trawler discards of American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), yellowtail flounder (*Limanda ferruginea*), and winter flounder (*Pseudopleuronectes americanus*), and to examine variables that potentially influence discard rates. Data were obtained from 135 tows in 6 areas of the Gulf of Maine. Four different types of trawls were used. Mean discard percentages per tow, on a weight basis, were 25, 18, 13, and 5% for American plaice, witch flounder, yellowtail flounder, and winter flounder, respectively. Mean discard percentages were higher on a numerical basis, with 57, 27, 25, and 12% of the respective species discarded per tow. Both trawl type and area fished affected the discard percentages of American plaice and witch flounder. Stepwise multiple regression analyses indicated that six variables combined to explain 66.8% of the variation in discard percentage of American plaice, and that three variables combined to explain 31.2% of the variation in discard percentage of witch flounder.
INTRODUCTION

Substantial numbers of unmarketable fish are retained by the gear in most trawl fisheries. Quite often a large portion of the unmarketable catch is composed of the juveniles and subadult stages of important commercial species. These are discarded at sea due to their small size. If some or all of these fish die as a result of the fishing operation, then each year class is subjected to some fishing mortality before it reaches marketable size. If this discard mortality is high, the clear implication is that recruitment potential, biomass, and yield are reduced significantly (Gulland 1973; Clark and Wood 1978). It is obvious that the discard rate must be known before this reduction can be quantified for consideration in stock assessment analyses. In addition, if variables which affect this rate could be identified, the fishing operation could be modified to reduce it.

Discard data are available for only a few fisheries despite their obvious importance. Even in these fisheries, which include the New England trawl fisheries, the data base is small and contains so much variation that it has limited application. This variation in discard estimates is not unexpected because neither fish nor fishing effort are uniformly distributed in space and time. Furthermore, the size and age distributions of the exploited populations change from area to area over time. In addition, the type of gear
used, the regulations in effect, marketing conditions, the composition of the catch, differences in year class strength, and the attitude of the captain and crew members will affect what is caught and what is discarded. The different ways in which discard data are collected also contribute to the variation in reported amounts. In most cases, discard information is obtained through captain interviews and logbook inspection. Unfortunately, these techniques produce intermittent and often unreliable results (Clark and Wood 1978; Jermyn and Robb 1981). Another method has been to place observers on commercial vessels during normal fishing operations (Jean 1963; Powles 1969; Bagge 1981; Jermyn and Robb 1981; Stevenson 1983). In the United States, this technique reached its fullest development in the "Sea Sampling" program developed by the National Marine Fisheries Service's Northeast Fisheries Center (Clark and Wood 1978). This program was designed to provide a continuous flow of data on catch per unit effort, length and age frequencies, and discards in the New England otter trawl fisheries. More recently, researchers at the same laboratory have developed techniques to estimate discards in mixed trawl fisheries from research vessel data (Mayo et al. 1981).

In this paper, the results of a preliminary study of trawler discards of American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), yellowtail flounder (*Limanda ferruginea*), and winter flounder (*Pseudopleuronectes americanus*) are described. Estimates of
weight, numbers, and size of discards and market fish were made by an
observer on a commercial trawler during normal fishing operations.
METHODS

From February through June of 1983 a total of 135 tows by a commercial trawler were examined for catch and discard of American plaice, witch flounder, yellowtail flounder, and winter flounder. Six areas in the Gulf of Maine were fished, ranging in depth from 40 to 183 m, and in bottom type from soft mud to sand-gravel-cobble composition (Figure 1-1). Four types of gear were used including a shrimp net with 4.45 cm mesh throughout, a Wilcox design trawl with 13.97 cm mesh throughout, a Yankee 35 trawl with 11.43 cm mesh in the body and 13.03 cm codend mesh, and a Yankee 41 trawl with 13.97 cm mesh throughout (Table 1-1). Except for two fishing trips for northern shrimp, the vessel sought several species. Flounders composed approximately 50% of the catch, with mixed groundfish (primarily cod, Gadus morhua, haddock, Melanogrammus aeglefinus, and smaller amounts of goosefish Lophius americanus, Atlantic wolffish, Anarhichas lupus, red hake Urophycis chuss, white hake, Urophycis tenuis) accounting for the remaining 50%.

The contents of each tow were culled into marketable (landed) and below market size (discard) flounders. Weights of the landed and discarded portions were estimated by the number of 49.90 kg fish boxes and 31.75 kg bushel baskets filled, respectively. When the discard was large, a representative
subsample was obtained by examining one-third of the total. Discard weights of each species from these subsamples were later expanded to account for the unsorted portions. The length-frequency distributions of the discarded flounder for most tows were obtained by measuring (total length of) either all, or a representative subsample of the discarded fish. The length-frequency distribution of the landed catch was obtained by randomly sampling 10 fish from each market category of each species. Numbers of fish landed and discarded were estimated by converting weights to numbers using ratios obtained by counting fish from samples of known weight. Because of this procedure, calculations based on numbers have some (unknown) sampling error associated with them. Discard percentages were obtained by dividing the number or weight of a species discarded by the total number or weight of that species caught in the trawl.

Date, time of day, air temperature, surface water temperature, gear type, duration and speed of tow, depth, and location (Loran C) were recorded for each tow. Also, bottom type was assigned a subjective value of 1 to 5 proceeding from soft (mud) to hard (rock-cobble). These values were determined by examining echo sounder traces and substrate adhering to trawl doors and net. Condition of the catch also was assigned a subjective value of 1 to 5 which represented the amount of material (e.g., boulders, mud, brittle stars) that could obstruct or close codend meshes and prevent escapement of small fish. Lower values were assigned to catches with little or no obstructive
material, and higher values were assigned to catches with more obstructive material.

Where possible, discard percentages (weight basis) from different areas and from different gear types were compared using analysis of variance (ANOVA) on the arcsin, square root-transformed data. Comparisons of discard percentages were made only between areas fished with the same gear type, and only between gear types fished in the same area. Mean lengths of discarded fish from different areas and from different gear types were compared with either ANOVA or Student t-tests.

Stepwise multiple regression analyses were used to determine the influence of combinations of independent variables on the arcsin, square root-transformed percent discard per tow (weight basis). Chosen independent variables included month, catch condition, depth, substrate type, gear type, and location. Both gear type and location were coded and entered as dummy variables. In the computer program that was used (STEPWISE REGRESSION, a procedure in STATPRO2), independent variables are entered into the regression equation one at a time according to decreasing values of their F-statistics. Only those variables that have F values with a probability level of 0.10 (two-tailed test) are included. Coefficient of determination (R²) values estimate the amount of variation in discard percentages explained by the selected combination of independent variables. Because of the small numbers of yellowtail and winter flounder in the areas fished, these species
were not considered in area and gear comparisons, nor were they analyzed using multiple regression.
RESULTS

Disposition of Total Flounder Catch

A total of 42,345 kg of flounder were caught in the 135 tows. Of this, 8,501 kg (20.1%) were discarded (Table 1-2). American plaice was the most common and abundant flounder species in the areas fished. Individuals were present in each of the 135 tows, and this species accounted for 74.4% of the total flounder catch. Of the 31,494 kg caught in all trips, 24,062 kg were landed for market and 7,432 kg were discarded at sea. This represents an overall discard of 23.6% (Table 1-2). Witch flounder were caught in 124 of the 135 tows and composed 15.5% of the total flounder catch. Total landings and discards were 5,692 and 865 kg respectively, for an overall discard of 13.2% (Table 1-2). Yellowtail flounder also were caught in 124 of the 135 tows but were less abundant than either American plaice or witch flounder. Of the 2,883 kg caught, 175 (6.1%) were discarded (Table 1-2). Winter flounder were scarce in the areas fished. Although some individuals were caught in 112 of the 135 tows, only a total of 1,411 kg were caught and 29 kg (2.1%) were discarded (Table 1-2).

Gear Effects

The mean discard percentage per tow varied among species within a gear
type and between gear types for any given species (Tables 1-3 thru 1-6). The shrimp trawl, used only in Scantum Basin, produced the highest discard percentage by both weight and number in virtually all cases. In only one case, yellowtail flounder (Table 1-5), the Yankee 35 trawl produced a slightly larger mean discard percentage on a weight basis. The second highest discard percentages were typically produced by the Yankee 35 trawl which was used in the Pasture and Ipswich Bay. This was true on both a weight and numerical basis for American plaice (Table 1-3) and winter flounder (Table 1-6), and on a numerical basis for witch (Table 1-4) and yellowtail flounder (Table 1-5). The two exceptions to this second place ranking are found in witch flounder (Table 1-4), where the Yankee 35 ranked third behind the Wilcox trawl on a weight basis, and in yellowtail flounder (Table 1-5) where, as already stated, the Yankee 35 trawl produced the greatest discard percentage on a weight basis. The Wilcox trawl used in all areas and the Yankee 41 trawl used in the Pasture and Ipswich Bay typically produced lower mean discard percentages than the other two gear types. The single exception was found in witch flounder (Table 1-4) where the Wilcox trawl produced a higher percentage of discards, on a weight basis, than the Yankee 35 trawl. Compared with other gear types, the Yankee 41 trawl had the lowest discards of American plaice and witch flounder (Tables 1-3 and 1-4) and the lowest discard of yellowtail flounder on a weight basis (Table 1-5). The Wilcox trawl had the lowest discard percentages for winter flounder (Table 1-6) and for yellowtail flounder on a
numerical basis (Table 1-5).

The only statistical gear comparisons that could be made were between (1) the shrimp trawl and the Wilcox trawl, (2) between the Wilcox trawl, the Yankee 35 trawl and the Yankee 41 trawl, and (3) between the Wilcox trawl and the Yankee 41 trawl because these were the only sets of gear used in the same areas at approximately the same times. Furthermore, the only species abundant enough to be considered were American plaice and witch flounder. Both the shrimp trawl and the Wilcox trawl were used in Scantum Basin. In this area, the mean discard of American plaice per tow using the shrimp trawl (73.1% on a weight basis) (Table 1-3) was significantly higher (ANOVA, \( P < 0.001 \)) than the mean discard of plaice per tow using the Wilcox trawl (25.0%). A similar result was seen for witch flounder (Table 1-4), where the mean discard per tow using the shrimp trawl (70.6%) was significantly higher (ANOVA, \( P < 0.005 \)) than the mean discard per tow using the Wilcox trawl (51.5%).

Gear type affected the size as well as the amount of discards. Plaice caught in the shrimp trawl ranged from 6.0 to 52.5 cm and witch flounder ranged from 10.7 to 52.7 cm (Figure 1-2). The Wilcox trawl caught larger individuals of both species; plaice ranged from 13.5 to 58.1 cm and witch flounder from 16.0 to 60.5 cm. Mean lengths of shrimp trawl discards were 22.7 cm (plaice) and 22.5 cm (witch flounder). These discards were significantly smaller (t-tests, \( P < 0.001 \)) than the mean lengths of plaice (28.1 cm) and witch flounder (27.5 cm).
discarded from the Wilcox trawl.

The Wilcox, Yankee 35, and Yankee 41 trawls were all used in the Pasture at approximately the same time. There were no significant differences (ANOVA, P > 0.5) between the mean discard percentages (weight basis) produced by these different types of gear for either American plaice (Table 1-3) or witch flounder (Table 1-4). The size ranges of American plaice and witch flounder caught by the Wilcox and Yankee 35 trawls in this area were similar, both catching plaice from about 15 to 61 cm and witch flounder from about 17 to 58 cm. There was no significant difference (t-test, P > 0.5) between the mean lengths of plaice discarded from the Wilcox trawl (27.7 cm) and the Yankee 35 trawl (26.9 cm). Similarly, there was no significant difference (t-test, P > 0.5) between the mean lengths of witch flounder discarded from the Wilcox trawl (26.6 cm) and the Yankee 35 trawl (26.7 cm). No discard length data were collected for either species when the Yankee 41 trawl was used in this area.

Both the Wilcox and Yankee 41 trawls were used repeatedly in Ipswich Bay. In this area, the Wilcox trawl produced a significantly greater (ANOVA, P < 0.005) percentage of plaice discards on a weight basis (24.8%) than the Yankee 41 trawl (16.5%) (Table 1-3). Similarly, the Wilcox trawl produced a significantly greater (ANOVA, P < 0.001) percentage of witch flounder discards on a weight basis (3.2%) than the Yankee 41 trawl (0.2%) (Table 1-4). Although these two gear types produced different discard percentages of both plaice and
witch flounder, the size range of specimens caught was not greatly different (Figure 1-3). Lengths of plaice caught by the Wilcox trawl ranged from 15.7 to 60.7 cm and the lengths of witch flounder from 16.0 to 59.7 cm. The Yankee 41 trawl caught plaice ranging from 19.2 to 60.7 cm long and witch flounder ranging from 18.2 to 60.0 cm. There was no significant difference (t-test, P > 0.05) between the mean lengths of plaice discarded from the Yankee 41 trawl (26.8 cm), and the mean length of plaice discarded from the Wilcox trawl (27.9 cm). Similarly, there was no significant difference (t-test, P > 0.05) between the mean lengths of witch flounder discarded from the Yankee 41 trawl (25.7 cm) and from the Wilcox trawl (27.6 cm). There were, however, fewer small witch flounder (< 30 cm) caught in Ipswich Bay with the Yankee 41 trawl (Figure 1-3).

Area Effects

There were large differences among the mean discard percentages per tow in the six areas fished (Tables 1-3 thru 1-6). For American plaice (Table 1-3), mean percent discard per tow on a weight basis was highest in Scantum Basin (52.5%) where both the shrimp and Wilcox trawls were used. The second highest mean discard percentage by weight was seen on Jeffreys Ledge (44.6%) where only the Wilcox trawl was used. Mean percent discard by weight was similar in the other areas, ranging from 27.4% (Pasture) to 19.4% (Ipswich Bay). In both the Pasture and Ipswich Bay, the Wilcox, Yankee 35, and Yankee 41 trawls were used while only the Wilcox net was employed on Platts Bank and
the Compass Rose. Mean discard percentages of plaice on a numerical basis showed a similar pattern, with the highest values in Scantum Basin (77.6%) and Jeffreys Ledge (77.8%) and lower values in the other areas.

For witch flounder (Table 4), mean discard percent per tow by weight also was highest in Scantum Basin (62.4%) and lowest in Ipswich Bay (1.1%). There was a similar pattern on a numerical basis, where mean percent discard was highest in Scantum Basin (86.2%) and lowest in Ipswich Bay (4.6%).

Using data obtained from the Wilcox trawl, which was used repeatedly in all six areas, we were able to compare discard percentages statistically between areas for both American plaice and witch flounder. Although mean discard percentage per tow (weight basis) varied between areas for both species, there were no significant differences (ANOVA, P > 0.1; Figures 4, 5) between areas for either species using this gear type. There was little difference in the overall size range of plaice and witch flounder caught in these areas (Figures 4 and 5) and no significant difference (ANOVA, P > 0.05) in the mean lengths of fish discarded from the different areas. The length-frequency distribution of American plaice caught on Jeffreys Ledge, however, showed a high proportion of pre-recruits and few market-size fish (Figure 1-4). The length-frequency distribution of witch flounder in Ipswich Bay showed a substantially greater proportion of market-size fish than the other areas (Figure 1-5).

The only other areas that could be statistically compared were the Pasture
and Ipswich Bay using data from the Yankee 4l trawl, that was used repeatedly in both areas at approximately the same time. Mean percent discard per tow on a weight basis was significantly higher (ANOVA, P < 0.01) for both species in the Pasture (34.8% plaice, 2.8% witch flounder) than it was in Ipswich Bay (2.8% plaice, 0.2% witch flounder (Tables 1-3 and 1-4). No statistical comparisons of discard lengths for either plaice or witch flounder were possible because no length data were collected in the Pasture when the Yankee 4l trawl was being used.

Multiple Regression

Six independent variables combined to explain 66.8% of the variation in percent discard by weight for American plaice (Table 1-7). These included, in decreasing order of importance, catch condition, month, gear type, bottom type, depth, and location. A smaller amount (31.2%) of the variation in witch flounder percent discard by weight was explained by the multiple regression model. Contributing independent variables, again in decreasing order of importance, were location, month, and catch condition (Table 1-7).
DISCUSSION

The results of this study indicated that discards represent a substantial portion of the Gulf of Maine flounder catch. Although other discard data from the Gulf of Maine are scarce, our estimates of percent discard, as well as the variation in discard rates, are similar to estimates obtained from other areas. Jean (1963) obtained data from both commercial and research vessels fishing off New Brunswick, Canada. Discards of American plaice ranged from 17 to 51% per tow by weight, and from 60 to 84% by number. Similarly, Powles (1969) found that American plaice discards near Magdalen Island, Canada ranged from 59 to 78% per tow by number. Lower estimates for plaice discards, 11.4% by weight and 26.9% by number, have been reported for the Newfoundland trawl fishery (Stevenson 1983). Discard estimates of other flounder species are similar, ranging from 20 to 40% for European plaice in the Baltic Sea (Bagge 1981), 28 to 32% in the southern New England yellowtail flounder fishery (Sissenwine et al. 1978; Mayo et al. 1981), and from 6 to 68% for winter flounder caught off the New England coast (Mayo et al. 1981). Our overall discard estimate for American plaice (23.5%) is within the range of values reported by others, but the overall estimates for winter flounder (2%) and yellowtail flounder (6%) are lower than other estimates for these species. Recall, however, that these estimates are based on relatively small sample
sizes. To my knowledge, this estimate of witch flounder discards (13.9% overall) is the first to be reported.

Virtually all the discard data contained a large amount of variation. Although some of this variation was due to small sample sizes, much of it probably was due to differences in gear used, in areas fished, in the relative abundances of small fish, and in the sizes selected for market. Among the variables that affect the amount of discard, the type of gear in use may be the most important. Results of this study indicated that flounder discard percentages were high in the northern shrimp fishery, presumably because the relatively fine mesh nets in use (4.45 cm) retain more small fish. It has been stated (unpublished draft of a fishery management plan for northern shrimp by the Northern Shrimp Scientific Committee, Woods Hole, Massachusetts) that the weight of finfish discarded in this fishery often equals or exceeds the amount of shrimp landed for market. In our study, the 4 tows made with shrimp gear yielded about 680 kg of shrimp while 335 kg of small flatfish were discarded. Although detailed discard estimates of other species such as silver hake (*Merluccius bilinearis*) and cod (*Gadus morhua*) were not made, it was our impression that the total weight of finfish discarded exceeded the weight of shrimp landed. A similar situation exists in the Gulf of Maine silver hake fishery where the small-mesh gear in use generates very high amounts of discard (Anderson 1975; Anderson and Almieda 1978).
The effect of mesh size also has been demonstrated for haddock
(*Melanogrammus aeglefinus*), where the numbers of discards on Georges
Bank decreased to a "negligible proportion of total catch" when mesh size was
increased from 11.43 to 13.97 cm (Martin and Jean 1958).

In addition to mesh size, the performance of the trawl, especially the way
its sweep interacts with the substrate, may affect the amount of discard. Our
comparison of discards from a Wilcox trawl and a Yankee 41 trawl, both of
which had 13.97 cm mesh, indicated that the Wilcox trawl produced
significantly greater discard percentages of American plaice and witch
flounder. We believe this was due to the Wilcox trawl digging deeper into
the substrate, thereby collecting more debris (e.g. rocks, mud, brittle stars)
which would obstruct and/or collapse the meshes and, thereby prevent
escapement. The fact that mean catch condition, an index we created to
quantify the amount of debris, was higher for the Wilcox net (2.41) than for
the Yankee 41 net (1.85) tends to support this belief.

This study also indicated that the area fished can affect the amount of
discard. Similar area effects have been noted for plaice (Powles 1969;
Stevenson 1983) and cod (Martin 1957). These results are not surprising
because fish tend to be distributed over particular substrates, depths, and
temperatures, all of which change from area to area. Furthermore, the
number of individuals and the size distribution of the population changes
over both area and time. We found that discards of witch flounder were
significantly higher in the Pasture than in Ipswich Bay. Adult witch flounder
normally move into shallower water to spawn (McKenzie 1955). This
spawning migration effectively separates the larger adults from the smaller
immature fish which remain in deep water (Powles and Kohler 1970).
Because spawning occurs in late spring and summer in the Gulf of Maine
(Bigelow and Schroeder 1953), it is likely that adults are leaving deeper areas
such as the Pasture (90-100 m) and are entering shallower areas such as
Ipswich Bay (40-70 m) at this time. Thus, our higher discard estimates of
witch flounder in the Pasture, obtained in March and April, probably were
due to the presence of a relatively large proportion of small individuals.
Conversely, the lower discard estimates in Ipswich Bay, obtained primarily in
May and June, probably were due to the large proportion of adults that had
moved into this area to reproduce. The fact that the size frequency
distributions of the catches in these two areas were quite different tends to
support our conclusions.

Area also affected the discard percentage of American plaice, with a
significantly higher percentage having been discarded in the Pasture than in
Ipswich Bay. As with witch flounder, it appears that the size distributions of
plaice in these areas are different. In the Pasture where discards were high, a
relatively large portion of the catch was composed of fish < 30 cm long. If we
assume the size frequency distribution of the catch reflects the population,
then discards were high in this area because of the disproportionate number
of small individuals. Conversely, discard percentages probably were lower in Ipswich Bay because proportionally less of the population was composed of fish < 30 cm long.

Stepwise multiple regression analyses indicated that six variables were important in explaining the variation in American plaice discard percentages. Among these variables, catch condition was the most important. The significant positive correlation ($r = 0.59, P < 0.01$) between this variable and discard percentage indicated that small plaice were unable to escape through the obstructed and/or collapsed codend meshes. The month of fishing, which was negatively correlated with percent discard ($r = -0.56, P < 0.01$), also was important. This negative correlation can be explained by the fact that fishing effort later in the year was in areas (primarily Ipswich Bay) where relatively small percentages of plaice were discarded. Location as well as substrate type and depth, which are location characteristics, also were included in the model. Because significant differences in the discard percentages exist between certain locations, at least when the Yankee 4l trawl was used it was not surprising that those independent variables were significant. Gear type also explained a portion of the variation in plaice discard percentage. Again, this was not unexpected, because significant differences in discard percentage exist between certain types of gear (e.g. shrimp and Wilcox trawl).

Three variables combined to explain 31.2% of the variation in witch flounder discard percentage. As already mentioned, the late spring spawning
migration effectively separates the smaller immature individuals from the larger spawning adults. Thus, different locations will have different proportions of large and small individuals during late spring and summer. Because of these differences and the fact that our samples were taken from several locations from February through June, it was not surprising that both location and month of fishing contributed to the variation in discard percentage. The third contributing variable was catch condition which was positively correlated \((r = 0.32, P < 0.01)\) with the witch flounder discard percentage. The more obstructive material there was in the net the higher the discard percentage, presumably because the small fish were unable to escape through the collapsed and/or obstructed meshes.

This study indicated that large amounts of flounder are discarded in the Gulf of Maine. The impact on the fishery will, of course, depend on the fraction of these discarded fish that die as a result of the fishing operation. Both Powles (1969) and Jean (1963) conducted mortality experiments with trawl-caught American plaice. In both studies, recently caught fish were subjected to varying lengths of deck exposure time. They found that after 30 min of exposure 95% of the fish died and that all were dead within 45 minutes. The culling operation on a trawler typically takes 30 to 45 min, and we must conclude that mortality is near 100%. This high rate of mortality, combined with the large percentages of fish being discarded, is undoubtedly reducing the potential yield in many fisheries. Unfortunately, considerably
more data are needed before ways to reduce the amount of discard can be formulated.

ACKNOWLEDGEMENTS

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REFERENCES


Table 1-1. Specifications of the gear used in the Gulf of Maine flounder discard study.

<table>
<thead>
<tr>
<th>Trawl type</th>
<th>Headrope length (meters)</th>
<th>Footrope length (meters)</th>
<th>Rise (meters)</th>
<th>Sweep</th>
<th>Mesh size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrimp</td>
<td>33.53</td>
<td>39.62</td>
<td>6.71</td>
<td>40.64 cm rollers</td>
<td>4.45</td>
</tr>
<tr>
<td>Wilcox</td>
<td>28.96</td>
<td>33.53</td>
<td>7.32</td>
<td>7.62 cm cookies</td>
<td>13.97</td>
</tr>
<tr>
<td>Yankee 35</td>
<td>15.24</td>
<td>21.34</td>
<td>2.44</td>
<td>12.70 cm cookies</td>
<td>11.43 (body), 13.03 (codend)</td>
</tr>
<tr>
<td>Yankee 41</td>
<td>26.52</td>
<td>32.61</td>
<td>3.66</td>
<td>15.24 cm cookies</td>
<td>13.97</td>
</tr>
</tbody>
</table>
Table 1-2. Disposition of the total catch of four flounder species from all 135 tows combined.

<table>
<thead>
<tr>
<th>Species</th>
<th>Weight caught (kg)</th>
<th>Landed weight (kg)</th>
<th>Discarded weight (kg)</th>
<th>Percent Discard</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Plaice</td>
<td>31,494</td>
<td>24,062</td>
<td>7,432</td>
<td>23.6</td>
</tr>
<tr>
<td>Witch Flounder</td>
<td>6,557</td>
<td>5,692</td>
<td>865</td>
<td>13.2</td>
</tr>
<tr>
<td>Yellowtail Flounder</td>
<td>2,883</td>
<td>2,708</td>
<td>175</td>
<td>6.1</td>
</tr>
<tr>
<td>Winter Flounder</td>
<td>1,411</td>
<td>1,382</td>
<td>29</td>
<td>2.1</td>
</tr>
<tr>
<td>All Flounders</td>
<td>42,345</td>
<td>33,844</td>
<td>8,501</td>
<td>20.1</td>
</tr>
</tbody>
</table>
Table 1-3. Mean (±1 SD) percent discard per tow by both weight (kg) and number for American Plaice. Calculations are based only on those tows in which some plaice were caught. Blanks in the matrix indicate no data for that trawl type and location. Number of tows in parentheses.

<table>
<thead>
<tr>
<th>Location and measure</th>
<th>Shrimp</th>
<th>Wilcox</th>
<th>Yankee 35</th>
<th>Yankee 41</th>
<th>All Trawls Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scantum Basin</td>
<td>(4)</td>
<td>(3)</td>
<td>(4)</td>
<td>(4)</td>
<td>(7)</td>
</tr>
<tr>
<td>Weight</td>
<td>73.1 ± 6.0</td>
<td>25.0 ± 3.3</td>
<td>23.5 ± 12.5</td>
<td>23.5 ± 12.5</td>
<td>52.5 ± 26.1</td>
</tr>
<tr>
<td>Number</td>
<td>94.6 ± 1.5</td>
<td>51.4 ± 6.3</td>
<td>55.2 ± 18.6</td>
<td>55.2 ± 18.6</td>
<td>77.6 ± 21.4</td>
</tr>
<tr>
<td>Platts Bank</td>
<td>(4)</td>
<td></td>
<td>(4)</td>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td>Weight</td>
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<td>23.5 ± 12.5</td>
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<tr>
<td>Number</td>
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<td></td>
<td></td>
<td></td>
<td>55.2 ± 18.6</td>
</tr>
<tr>
<td>Jeffrey's Ledge</td>
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<td></td>
<td>(3)</td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>Weight</td>
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<td></td>
<td></td>
<td></td>
<td>44.6 ± 10.5</td>
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<tr>
<td>Number</td>
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<td></td>
<td></td>
<td></td>
<td>77.8 ± 6.3</td>
</tr>
<tr>
<td>Pasture</td>
<td>(53)</td>
<td>(2)</td>
<td>(2)</td>
<td>(57)</td>
<td>(57)</td>
</tr>
<tr>
<td>Weight</td>
<td>27.3 ± 11.4</td>
<td>22.1 ± 0.2</td>
<td>34.8 ± 2.9</td>
<td>27.4 ± 11.1</td>
<td>27.4 ± 11.1</td>
</tr>
<tr>
<td>Number</td>
<td>59.5 ± 14.7</td>
<td>56.3 ± 0.3</td>
<td>72.1 ± 2.6</td>
<td>59.0 ± 14.0</td>
<td>59.0 ± 14.0</td>
</tr>
<tr>
<td>Ipswich Bay</td>
<td>(18)</td>
<td>(1)</td>
<td>(42)</td>
<td>(61)</td>
<td>(61)</td>
</tr>
<tr>
<td>Weight</td>
<td>24.8 ± 9.1</td>
<td>42.6 ± 0.0</td>
<td>16.5 ± 8.6</td>
<td>19.4 ± 9.9</td>
<td>19.4 ± 9.9</td>
</tr>
<tr>
<td>Number</td>
<td>60.2 ± 11.1</td>
<td>77.1 ± 0.0</td>
<td>46.7 ± 14.8</td>
<td>51.1 ± 15.3</td>
<td>51.1 ± 15.3</td>
</tr>
<tr>
<td>Compass Rose</td>
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<td>(3)</td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>Weight</td>
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<td></td>
<td>21.2 ± 4.4</td>
</tr>
<tr>
<td>Number</td>
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<td>49.7 ± 6.2</td>
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<tr>
<td>All Locations Combined</td>
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<td>(3)</td>
<td>(42)</td>
<td>(135)</td>
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<tr>
<td>Weight</td>
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<td>26.9 ± 11.0</td>
<td>29.0 ± 11.8</td>
<td>17.3 ± 9.3</td>
<td>25.2 ± 14.0</td>
</tr>
<tr>
<td>Number</td>
<td>94.6 ± 1.5</td>
<td>59.6 ± 14.4</td>
<td>63.2 ± 12.0</td>
<td>48.3 ± 15.5</td>
<td>56.7 ± 16.6</td>
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</table>
Table 1-4. Mean (±1 SD) percent discard per tow by both weight (kg) and number for Witch Flounder. Calculations are based only on those tows in which some witch flounder were caught. Blanks in the matrix indicate no data for that trawl type and location. Number of tows in parentheses.

<table>
<thead>
<tr>
<th>Location and measure</th>
<th>Shrimp</th>
<th>Wilcox</th>
<th>Yankee 35</th>
<th>Yankee 41</th>
<th>All Trawls Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
<td>(3)</td>
<td>(7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scantum Basin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>70.6 ± 5.0</td>
<td>51.5 ± 0.6</td>
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<td></td>
<td>62.4 ± 10.8</td>
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<td>Number</td>
<td>94.2 ± 1.1</td>
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<td>86.2 ± 10.6</td>
</tr>
<tr>
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<td>Weight</td>
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<td></td>
<td></td>
<td></td>
<td>39.6 ± 6.0</td>
</tr>
<tr>
<td>Jeffrey's Ledge</td>
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<td>(3)</td>
<td>(3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>19.3 ± 1.7</td>
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<td>(42)</td>
<td>(2)</td>
<td>(2)</td>
<td>(46)</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
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<td>2.8 ± 4.0</td>
<td>34.2 ± 40.8</td>
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</tr>
<tr>
<td>Number</td>
<td>48.0 ± 39.0</td>
<td>56.3 ± 0.3</td>
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<tr>
<td>Ipswich Bay</td>
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<td>(1)</td>
<td>(42)</td>
<td>(61)</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>3.2 ± 3.4</td>
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<td>1.1 ± 2.3</td>
<td></td>
</tr>
<tr>
<td>Number</td>
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</tr>
<tr>
<td>Compass Rose</td>
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<td>(3)</td>
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<td></td>
</tr>
<tr>
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</tr>
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<td>Weight</td>
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<tr>
<td>Number</td>
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<td>39.4 ± 35.5</td>
<td>42.3 ± 32.7</td>
<td>2.1 ± 5.3</td>
<td>27.4 ± 34.7</td>
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Table 1-5. Mean (±1 SD) percent discard per tow by both weight (kg) and number for Yellowtail Flounder. Calculations are based only on those tows in which some yellowtail flounder were caught. Blanks in the matrix indicate no data for that trawl type and location. Number of tows in parentheses.

<table>
<thead>
<tr>
<th>Location and measure</th>
<th>Shrimp</th>
<th>Wilcox</th>
<th>Yankee 35</th>
<th>Yankee 41</th>
<th>All Trawls Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scantum Basin</td>
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<td>(1)</td>
<td></td>
<td></td>
<td>(5)</td>
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<tr>
<td>Weight</td>
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<td>Number</td>
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<td></td>
<td>80.6 ± 15.4</td>
</tr>
<tr>
<td>Platts Bank</td>
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<td>(3)</td>
</tr>
<tr>
<td>Weight</td>
<td>100.0 ± 0.0</td>
<td></td>
<td></td>
<td></td>
<td>100.0 ± 0.0</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>100.0 ± 0.0</td>
</tr>
<tr>
<td>Jeffrey's Ledge</td>
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<td></td>
<td>(1)</td>
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<td>Weight</td>
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<td>100.0 ± 0.0</td>
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<td></td>
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<td>(55)</td>
</tr>
<tr>
<td>Weight</td>
<td>7.4 ± 15.6</td>
<td>19.8 ± 19.2</td>
<td>11.5 ± 16.3</td>
<td></td>
<td>8.8 ± 15.6</td>
</tr>
<tr>
<td>Number</td>
<td>15.3 ± 21.4</td>
<td>45.5 ± 31.7</td>
<td>28.1 ± 39.8</td>
<td></td>
<td>17.2 ± 23.5</td>
</tr>
<tr>
<td>Ipswich Bay</td>
<td>(17)</td>
<td>(1)</td>
<td>(42)</td>
<td></td>
<td>(60)</td>
</tr>
<tr>
<td>Weight</td>
<td>5.6 ± 8.9</td>
<td>100.0 ± 0.0</td>
<td>9.0 ± 7.8</td>
<td></td>
<td>9.5 ± 14.4</td>
</tr>
<tr>
<td>Number</td>
<td>60.2 ± 11.1</td>
<td>100.0 ± 0.0</td>
<td>23.5 ± 10.7</td>
<td></td>
<td>23.5 ± 18.3</td>
</tr>
<tr>
<td>Compass Rose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Locations</td>
<td>(4)</td>
<td>(73)</td>
<td>(3)</td>
<td>(44)</td>
<td>(124)</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>41.7 ± 16.7</td>
<td>13.3 ± 27.3</td>
<td>46.5 ± 48.3</td>
<td>9.1 ± 8.0</td>
<td>13.5 ± 23.7</td>
</tr>
<tr>
<td>Number</td>
<td>75.4 ± 12.4</td>
<td>21.8 ± 30.1</td>
<td>63.4 ± 39.1</td>
<td>23.5 ± 12.2</td>
<td>25.0 ± 27.0</td>
</tr>
</tbody>
</table>
Table 1-6. Mean (±1 SD) percent discard per tow by both weight (kg) and number for Winter Flounder. Calculations are based only on those tows in which some winter flounder were caught. Blanks in the matrix indicate no data for that trawl type and location. Number of tows in parentheses.

<table>
<thead>
<tr>
<th>Location and measure</th>
<th>Shrimp</th>
<th>Wilcox</th>
<th>Yankee 35</th>
<th>Yankee 41</th>
<th>All Trawls Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scantum Basin</td>
<td>(4)</td>
<td></td>
<td></td>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td>Weight</td>
<td>25.0 ± 28.9</td>
<td></td>
<td></td>
<td></td>
<td>25.0 ± 28.9</td>
</tr>
<tr>
<td>Number</td>
<td>41.9 ± 48.5</td>
<td></td>
<td></td>
<td></td>
<td>41.9 ± 48.5</td>
</tr>
<tr>
<td>Platts Bank</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Weight</td>
<td>100.0 ± 0.0</td>
<td></td>
<td></td>
<td></td>
<td>100.0 ± 0.0</td>
</tr>
<tr>
<td>Number</td>
<td>100.0 ± 0.0</td>
<td></td>
<td></td>
<td></td>
<td>100.0 ± 0.0</td>
</tr>
<tr>
<td>Jeffrey's Ledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>(49)</td>
<td>(2)</td>
<td>(2)</td>
<td>(53)</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>4.6 ± 14.8</td>
<td>11.9 ± 22.3</td>
<td>11.9 ± 22.3</td>
<td>11.9 ± 22.3</td>
<td></td>
</tr>
<tr>
<td>Pasture</td>
<td>(14)</td>
<td>(40)</td>
<td>(42)</td>
<td>(112)</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>2.4 ± 8.9</td>
<td>2.8 ± 6.2</td>
<td>2.7 ± 6.9</td>
<td>2.7 ± 6.9</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>60.2 ± 11.1</td>
<td>8.8 ± 18.1</td>
<td>8.3 ± 19.4</td>
<td>8.3 ± 19.4</td>
<td></td>
</tr>
<tr>
<td>Compass Rose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>(64)</td>
<td>(2)</td>
<td>(42)</td>
<td>(112)</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>5.3 ± 15.7</td>
<td>11.6 ± 23.7</td>
<td>11.6 ± 23.7</td>
<td>11.6 ± 23.7</td>
<td></td>
</tr>
</tbody>
</table>

31
Table 1-7. Percentages of the variation ($R^2$) in discard percentage (weight basis) explained by the indicated independent variables. Each row represents a step in the statistical procedure. Increases in $R^2$ associated with the step, and the final stepwise multiple regression models also are given. CC = catch condition, MTH = month, GR = gear, SUB = substrate, DPTH = depth, LOC = location.

<table>
<thead>
<tr>
<th>Variables</th>
<th>R²</th>
<th>Increase in R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Plaice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>35.1</td>
<td>14.1</td>
</tr>
<tr>
<td>CC + MTH</td>
<td>49.2</td>
<td>5.8</td>
</tr>
<tr>
<td>CC + MTH + GR</td>
<td>55.0</td>
<td>8.5</td>
</tr>
<tr>
<td>CC + MTH + GR + SUB</td>
<td>63.5</td>
<td>2.0</td>
</tr>
<tr>
<td>CC + MTH + GR + SUB + DPTH</td>
<td>65.5</td>
<td>1.3</td>
</tr>
<tr>
<td>CC + MTH + GR + SUB + DPTH + LOC</td>
<td>66.8</td>
<td></td>
</tr>
<tr>
<td>Percent Discard = 65.46 + 4.18 CC - 3.45 MTH - 9.68 GR - 6.74 SUB - 0.19 DPTH + 8.48 LOC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Witch Flounder                |     |                |
| LOC                           | 25.8| 3.5            |
| LOC + MTH                     | 29.3| 1.9            |
| LOC + MTH + CC                | 31.2|                |
| Percent Discard = 43.40 - 14.93 LOC - 6.44 MTH + 3.77 CC |

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Figure 1-1. Areas fished in the Gulf of Maine: IB = Ipswich Bay; SB = Scantum Basin; P = Pasture; JL = Jeffreys Ledge; PB = Platts Bank; and CR = Compass Rose
Figure 1-2. Length-frequency distributions of American plaice and witch flounder caught in Scantum Basin using a shrimp trawl and a Wilcox trawl: o o = discards; + + = landed fish.
Figure 1-3. Length-frequency distributions of American plaice and witch flounder caught in Ipswich Bay using a Wilcox trawl and a Yankee 41 trawl: o____o = discards; +____+ = landed fish.
Figure 1-4. Length-frequency distributions of American plaice caught with a Wilcox trawl in the indicated locations: o o = discards; + + = landed fish.
Figure 1-5. Length-frequency distributions of witch flounder caught with a Wilcox trawl in the indicated locations: o o o = discards; + + + = landed fish.
PART 2. DISCARDING OF COMMERCIAL GROUNDFISH SPECIES
IN THE GULF OF MAINE SHRIMP FISHERY
ABSTRACT

The objective of the research was to quantify discards of American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), goosefish (*Lophius americanus*), silver hake (*Merluccius bilinearis*), and cod (*Gadus morhua*) in the Gulf of Maine shrimp fishery. Data were obtained from 50 tows made by commercial trawlers fishing in the southwestern Gulf of Maine. Mean discard percentages per tow, on a weight basis, were: 93% for silver hake, 87% for American plaice, 76% for witch flounder, 56% for cod, 41% for goosefish, 20% for yellowtail flounder, and 11% for winter flounder. Mean discard percentages per tow on a numerical basis were slightly higher. Neither catch condition nor tow duration affected discard percentage, but discard percentage decreased with increasing depth for American plaice.
INTRODUCTION

Variable amounts of small, unmarketable fish, including the juveniles and subadults of commercially important species, are caught in most demersal trawl fisheries. These individuals are discarded at sea. Studies conducted by Jean (1963), Hoag (1975), de Veen et al. (1975), Schott (1975), and Rogers et al. (1986) all indicate that mortality of these individuals is high. The implications of discarding and discard mortality have been reviewed by Saila (1983), and include reductions of recruitment, biomass, and future yield, and the potential, but largely unknown, ecological impacts of removing predators, prey and competitors. It is obvious that accurate estimates of discard rates and mortality are critical for stock assessment analyses and management.

The destruction of small fish by trawling has been recognized for many years. Herrington (1935) noted that "large numbers of undersized food fish (were) captured and destroyed by nets" in the New England otter trawl fishery. Discards in this fishery have since been quantified by S.H. Clark and P.W. Wood, National Marine Fisheries Service (NMFS), unpublished data; R.K. Mayo, A.M. Lange, and colleagues, NMFS, unpublished data; Howell and Langan (1987); and M.P. Sissenwine, B.E. Brown, and M.M. McBride (NMFS, unpublished data). Information on discards is also available for Canadian trawl fisheries (Jean, 1963; Stevenson, 1978, 1980-83; Kulka, 1985, 1986a,b;
Halliday et al., 1989; W.R. Martin and Y. Jean, Fisheries Research Board of Canada (FRBC), unpublished data); North Sea cod, haddock, and whiting fisheries (Jermyn and Robb, 1981), Baltic Sea groundfish fishery (Bagge, 1981), and for the Bering Sea groundfish fishery (Wespestad et al., 1982). Shrimp fisheries typically generate high numbers of discards because of the relatively small mesh trawls that are employed. Discard data for the United States penaeid shrimp fisheries were reviewed by Slavin (1982), Saila (1983), and B. Rothschild and J.A. Gulland (NMFS, unpublished data).

Otter trawl fisheries for northern shrimp, *Pandalus borealis*, exist on the west coast of North America, in the Canadian maritime provinces, on the west coast of Greenland, and in the Norwegian and North Seas. A seasonal (typically December through May) northern shrimp fishery has existed in the western Gulf of Maine since 1937 (Haynes and Wigley, 1969). In the 1988-89 season, approximately 7.1 million pounds of shrimp were landed by vessels fishing from ports in Maine, New Hampshire, and Massachusetts. Some information on bycatch and discard rates have been reported from northern shrimp fisheries in the North Sea (Poulsen, 1970), off western Greenland (Ulltang and Oynes, 1978), near Baffin Island (Minet et al., 1978), and the western Gulf of Maine (Howell and Langan, 1987). Since the vast majority of shrimp in these fisheries are caught using small mesh otter trawls, it is not surprising that the limited data indicate that discard rates are relatively high.

In this section, the results of a study of shrimp trawler discards of
American plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*), witch flounder (*Glyptocephalus cynoglossus*), winter flounder (*Pseudopleuronectes americanus*), cod (*Gadus morhua*), silver hake (*Merluccius bilinearis*), and goosefish (*Lophius americanus*) in the southwestern Gulf of Maine are described. Estimates of discard percentages by both weight and number, sizes of discards, and discard weights per unit effort are reported. We also examined the relationships between discard percentage and tow duration and catch condition.

The data reported in this paper were obtained prior to implementation of gear regulations intended to reduce finfish bycatch in the shrimp fishery.
METHODS

A total of fifty tows, made by six different commercial trawlers fishing for northern shrimp in the southwestern Gulf of Maine (Fig. 2-1), were examined between 1985 and 1989. All sampling was opportunistic and occurred in Jeffreys Basin (26 tows), Scantum Basin (19 tows), and Ipswich Bay (5 tows). It is within these largely confluent areas that many of the New Hampshire, southern Maine, and northern Massachusetts trawlers fish for shrimp. Data were collected from December through March, but because sampling was opportunistic, not all areas were sampled each month (Table 2-1). Towing depths ranged from 71-137 meters, and substrate type was generally soft mud. Five different size shrimp trawls were employed. In each, the stretch mesh size (knot to knot) was 4.45 cm throughout the net. Headrope lengths ranged from 11-34 m, footrope lengths from 16-40 m, and rise from 2.5-6.7 m. All nets had sweeps made up of rubber rollers (20-41 cm) and 7.5-12.7 cm "cookies" (small rubber discs) threaded onto a wire cable. Date, time of day, gear information, water depth, duration and speed of tow, and location (Loran C) were recorded for each tow. Condition of the catch was assigned a subjective value of one to five which represented the amount of material (e.g. mud, brittlestars, skates, boulders) that could obstruct or close codend meshes and prevent the escapement of small fish. Lower values were
assigned to catches with little obstructive material, and higher values to catches with more obstructive material.

The content of each tow was separated into shrimp, marketable finfish (landed), and below market size (discarded) finfish. All sorting was done by the crew and one or more observer. There was no reason to believe that sorting was any different than usual because of an observer's presence. Catches and discards of American plaice, witch flounder, yellowtail flounder, winter flounder, cod, silver hake, and goosefish were quantified. Weights of the landed and discarded fractions of each species were estimated by the number of 50 kg fish boxes or 32 kg baskets filled. When the finfish catch was large, a representative subsample was obtained by examining one-fifth to one-third of the total. The subsamples were expanded to account for the unsorted portions. Numbers of each species landed and discarded were either directly counted or estimated by converting weights to numbers using ratios obtained by counting fish in samples of known weight. Because of this procedure, some calculations based on numbers have some unknown sampling error associated with them. All, or a representative subsample of each species in each tow, were measured (total length) to the nearest centimeter.

Discard percentages were obtained by dividing the number or weight of a species discarded by the total number or weight of that species caught in the trawl. In the results, these two values are reported as discard percentage on a
weight basis, followed, in parentheses, by discard percentage on a numerical basis. Since catch condition is a categorical variable, its effect on percent discard (weight basis) was examined using one-way analysis of variance (ANOVA) on the arcsine square-root-transformed data (Sokal and Rohlf, 1969). For each species, functional linear regression (Ricker, 1973) was used to examine the relationship between the arcsine square-root-transformed percent discard (weight basis) and the independent variables of depth (meters) and tow duration (hrs). The relationship between depth and discard percentage was examined since it was known that in at least one species (witch flounder) different sized individuals occupy different depths, and that this could affect discard percentage. Tow duration was examined because we felt that the longer the tow, the more obstructed the codend meshes might become, and catch condition has formerly been shown to affect discard percentage (Howell and Langan, 1987). It was not possible to analyze the effect of substrate type since virtually all tows were made over soft mud bottom, and no attempt was made to compare different shrimp trawls since each was used on a different vessel. Lastly, areas fished and months were not compared since no single vessel made a sufficient number of tows in each of the different areas, or in the same area each month.
RESULTS

Disposition of Total Catch

Of the finfish caught, 79.9% were discarded (Table 2-2). Silver hake was the most abundant species caught, with varying amount present in 43 of the 50 tows. American plaice were second in abundance, and were present in all 50 tows. Cod and winter flounder ranked third and fourth in finfish catch, and were taken in 37 and 48 of the 50 tows, respectively. Witch flounder, yellowtail flounder, and goosefish were considerably less abundant in the area fished. Less than 227 kg of each was caught, and they were present in only 31, 39, and 30 of the 50 tows, respectively.

Per Tow Summary

On a per tow basis (Table 2-3), on the average, more pounds of shrimp were landed for market than finfish. No shrimp were discarded, but an average of 210 lbs of finfish were discarded in each tow. The average number of finfish landed was very low, 142, while the average number discarded was 2,881, resulting in an average finfish discard percentage of 67.8% on a weight basis and 93.4% on a numerical basis.

Species Summary

The mean percent discard per tow, by weight and number, for each of
the fish species is given in Table 2-4. Percentages are based only on those tows in which some individuals of the indicated species were caught. In some cases, the number of tows (n) differs for the two percentages since the number of discards of some species was not recorded in some tows. American plaice discard percentages were highest among the flatfish species, then came witch flounder, followed by yellowtail and winter flounders, which were discarded at much lower rates. Among the roundfish, average discard percentages were greatest for silver hake, then cod and goosefish.

Mean numbers and weights discarded per tow are given in Table 2-5, and are calculated in two different ways. In the first method, we used only those tows in which some individuals of the given species were present in the catch. In the second, mean values were calculated based on all 50 tows, regardless of whether or not the particular species was present. Values obtained using the first method provide estimates of numbers and weights discarded in tows which caught some individuals of the indicated species. Values obtained using the second method are useful in gauging the impact of shrimp trawler discards, since they represent the "average" tow which, in our case, lasted 3.14 hours. More than 1600 silver hake, nearly 790 American plaice, and about 78 cod are discarded in the average shrimp tow. Substantially fewer witch flounders, yellowtail flounders, winter flounders, and goosefish are discarded in the average tow. The same pattern emerges on
a weight basis. More than 91 kg of silver hake, more than 45 kg of American plaice, and more than 22.7 kg of cod are discarded in the average tow. The average weight of the other four species discarded per tow was less than 2.7 kg each.

Independent Variables

Mean (± 2 SE) depth, duration, and catch condition of the 50 tows were 110 ± 5.5 m, 3.1 ± 0.3 hrs, and 1.6 ± 0.3 units. Catch condition had no affect on percent discard (weight basis) for any of the seven species examined (P>0.10), and there was no functional linear relationship between percent discard (weight basis) and tow duration for any of the species (P>0.05). Cod, goosefish, yellowtail flounder, and winter flounder discard percentages (weight basis) were not linearly related to towing depth (P>0.05). For silver hake, witch flounder, and American plaice, discard percentage (weight basis) decreased with increasing depth (Table 2-6).

Length Frequencies

The length frequency distributions of discarded American plaice, witch flounder, cod, and silver hake are shown in Figures 2 and 3. Mean total lengths of plaice, witch flounder, cod, and silver hake were 20.5, 20.7, 31.1, and 17.6 cm, respectively. Too few winter flounder, yellowtail flounder, and
goosefish were measured to generate meaningful length frequency
distributions. The ranges of discard lengths for winter flounder, yellowtail
flounder, and goosefish were 17-28, 18-28, and 13-36 cm TL, respectively.
Mean discard length was 24.4 cm TL for winter flounder, 26.0 cm TL for
yellowtail flounder, and 22.8 cm TL for goosefish.
DISCUSSION

General Finfish Discard

This study indicates that discards of certain fish species are relatively high in the Gulf of Maine shrimp fishery. Indeed, the suggestion made by R.G. Rinaldo, B.E. Barrett, D.B. Mac Isaac, K. Smith, and P.D. Colisi (State-Federal Northeast Fishery Management Board, unpublished data) that the discard of finfish in directed northern shrimp fishing operations may equal or exceed the total shrimp catch, is confirmed in this study. In the 50 tows examined, a total of 8,827 kg of the 7 species under study were discarded. This exceeded the total shrimp catch of 7,764 kg. Viewed slightly differently, there were 1.14 kg of finfish discarded for every pound of shrimp landed. This estimate is conservative since the discards of hake, herring, sculpins, skates, etc. were not included.

 Comparable discard information from other northern shrimp fisheries is limited. Poulsen (1970), while conducting shrimp surveys in the North Sea and Skagerrak regions, observed that 87% of the total catch from 34 separate shrimp tows was finfish bycatch, most of which was discarded. Total bycatch percentage in this study, defined as the total weight of the 7 species of finfish caught (11,045 kg) divided by the total catch of both shrimp and finfish (18,809 kg) was about 59%. Had all fish species been considered, as Poulsen did, the
bycatch percentage would have been very similar to his estimate. Even though many of the >30 finfish species caught and discarded by Poulsen were commercially important (e.g. cod, plaice, long rough dab, haddock), he concluded that the associated loss of recruitment was negligible since the shrimp fishery was fairly small. This is clearly not the case in the Gulf of Maine shrimp fishery. In the 1988-89 season, for example, a total of 9,610 fishing trips were made by vessels from Maine, New Hampshire, and Massachusetts (P. Diodati, Atlantic States Marine Fisheries Commission, personal communication). This level of activity, combined with the high bycatch and discard percentages, is likely having a negative impact on the groundfish and flounder fisheries in this area. Bycatch and discard information from other northern shrimp fisheries indicate similar problems. Ulltang and Oynes (1978), while conducting shrimp surveys in west Greenland waters, noted that in some tows as many as 10,000 redfish (Sebastes sp.) and >900 Greenland halibut (Reinhardtius hippoglossoides) were caught. Of these, most were less than the minimal size that would have been retained for market. Minet et al. (1978) also found that small redfish and Greenland halibut dominated the bycatch in shrimp tows made off Baffin Island, and that most were of a size that would have been discarded by a commercial vessel. Although some Pacific halibut (Hippoglossus stenolepis) are caught incidentally in the northern shrimp fisheries of the Gulf of Alaska and Bering Sea (Williams et al., 1989), the small number caught (<5 fish per metric ton of...
shrimp) indicates that the problem is not serious in this fishery. To the best of my knowledge, the only published estimates of discards in the Gulf of Maine shrimp fishery are preliminary ones presented in Part 1. From data collected aboard commercial vessels during normal fishing operations, it was estimated that on a weight basis, 73.1% of the American plaice, 70.6% of the witch flounder, 41.7% of the yellowtail flounder, and 25.0% of the winter flounder were discarded. Percentages were higher on a numerical basis with 94.6, 94.2, 75.4, and 41.9% discarded for the respective species.

Specific Finfish Discards

Plaice

In the present study, American plaice were the most common flatfish observed, with some caught in each of the 50 tows. Discard percentages on both a weight (81.4%) and numerical (96.8%) basis were higher than for any of the other flounder species, and relatively large numbers and weights were discarded in the average tow. This same pattern was seen in the preliminary study of the northern shrimp fishery (Part 1). American plaice discard estimates from other trawl fisheries are numerous. These include studies conducted in the Gulf of St. Lawrence (Jean, 1963; Powles, 1969; Halliday et al., 1989), off Newfoundland (Stevenson, 1978, 1980-83; Kulka, 1985, 1986a,b), off Nova Scotia (Belzile, 1978), and in the western Gulf of Maine (Part 1). Discard estimates vary, depending on location and year, from <2 to about 60% by
weight, and from about 16-85% by number. Discard estimates of plaice in the present study exceed all of these, presumably because the relatively small mesh nets employed in the shrimp fishery retain greater numbers of small fish, thereby increasing discard amounts. The effect of mesh size was examined in the previous study (Part 1) where discard percentages from tows made with a small mesh (4.45 cm) shrimp trawl were compared to those made with a larger codend mesh (13.97 cm) flounder net. In these tows, made in the same area at about the same time, both American plaice and witch flounder discard percentages were significantly higher when the shrimp trawl was used. Additionally, the mean lengths of plaice and witch flounder discards were significantly shorter than those from the flounder net.

The sizes of American plaice discards, 7-33 cm, indicates that they ranged from 1-4 years of age (Bigelow and Schroeder, 1953), with most being 2 or 3 years old. Most individuals of these sizes and ages are still sexually immature.

Witch flounder

This species was considerably less abundant than American plaice. They were present in only 31 of the 50 tows, and only 183 kg were caught. Although discard percentages were relatively high, only about 17 individuals and about 2.3 kg were discarded in the average tow. The low abundance of witch flounder observed in this study is not surprising. Although they prefer
the soft, muddy substrates typical of the areas fished (Scott, 1982), it is likely that the greatest concentrations of witch flounder were located in deeper water. In this study, towing depths ranged from 71-137 m, and Powles and Kohler (1970), Markle (1975), and Walsh (1987) have all found that small witch flounder are most abundant at depths >183 m. As was the case for American plaice, the present estimates of witch flounder discard percentages are similar to those in the preliminary study (Part 1). Several other discard estimates are available for witch flounder. Stevenson (1978) and Kulka (1985, 1986a,b) estimated that witch flounder discard rates ranged from 0.5-29.0% (weight basis) off Newfoundland and Labrador, and that discard rates differed between areas. Howell and Langan (1987) estimated witch flounder discards from the western Gulf of Maine to be about 18.4% by weight and 27.4% by number when relatively large codend mesh (13.03 and 13.97 cm) nets were used. Because of the small mesh nets used in the northern shrimp fishery, it is not surprising that the estimates of witch flounder discards in this study are considerably higher than in any of the aforementioned studies. While mesh size almost certainly explains some of the observed differences, both Powles and Kohler (1970) and Walsh (1987) found that small witch flounder were more vulnerable to shrimp trawls than to otter trawls. Walsh (1987) suggested that this was due to some difference in behavioral response to the different gear types.

Witch flounder discards ranged from 9-34 cm in length, which would

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indicate ages ranging from 2-4 years (Bigelow and Schroeder, 1953). Since sexual maturity is not reached until the fish are older (Bowering, 1978), it is highly probable that all discarded individuals were sexually immature.

Yellowtail flounder

These fish were the least abundant flatfish in the area. They were present in 39 of the 50 tows, and only 156 kg were caught. There were <3 individuals and <0.9 kg discarded in the average tow. Their scarcity probably results from their preference for sand or sand-mud substrates (Scott, 1982) that are not typical of the study area. Discard percentages seen in this study, about 20% by both weight and number, are much lower than previous estimates from the same fishery (Part 1). The larger number of tows in the present study leads one to believe that the present estimates are more reliable. Estimates of yellowtail flounder discard percentages in other fisheries are quite variable. Stevenson (1978) gives estimates of 13.8% by weight and 29.4% by number for otter trawlers fishing off Newfoundland and Labrador. These are very close to the estimates of 13.5% by weight and 25.0% by number reported for the western Gulf of Maine (Howell and Langan, 1987). Lower rates, 3.7-5.5% by weight, have been reported off Newfoundland (Kulka, 1985, 1986a,b), and higher rates, 28-32% by weight, have been suggested for Georges Bank and southern New England (M.P. Sissenwine et al., NMFS, unpublished data; Mayo et al., NMFS, unpublished data). It can be seen that
yellowtail flounder discard percentages in the northern shrimp fishery are similar to those reported in some large mesh groundfish and flounder fisheries, and are relatively low compared to most of the other species reported in this study. These results, combined with the very small numbers discarded in the average tow, indicate that the northern shrimp fishery is not having a significant adverse effect on the inshore Gulf of Maine yellowtail flounder population.

Yellowtail flounder discards ranged from 18-28 cm, which indicates most were less than 2 years old (Lux and Nichy, 1969). Because sexual maturity is attained at 2-4 years for females and 2-3 years for males (Royce et al., 1959), some of the discards, especially the larger males, may have been sexually mature.

Winter flounder

Winter flounder were the second most abundant flatfish species. More than 455 kg were caught, and some were present in 48 of the 50 tows. Discard percentages by both weight and number were lower for this species than for any of the others, and only about 7 individuals and 1.8 kg were discarded in the average tow. As was the case with yellowtail flounder, current estimates of winter flounder discards in the shrimp fishery are considerably lower than previous estimates (Part 1). Presumably, the current estimates are better because of the larger sample size. To my knowledge, only two other studies
have dealt with winter flounder discards. R.K. Mayo et al. (NMFS unpublished data), estimated discards in several mixed trawl fisheries from bottom trawl survey catches, and indicated that discards of winter flounder varied considerably between fisheries. Their simulations suggested, for example, that none were discarded in the New England Loligo squid and scup (Stenotomus chrysops) fishery, while in other fisheries (e.g. mixed trawl fisheries on Georges Bank) the ratio of discards to landings exceeded 1.6:1. Their overall estimate of winter flounder discards was 46.6% on a weight basis. Howell and Langan (1987) estimated that 5.3% (weight basis) and 11.6% (numerical basis) of the winter flounder were discarded in the western Gulf of Maine flounder and groundfish fishery. Somewhat surprisingly, present estimates from the northern shrimp fishery are only slightly higher than the 1987 estimates from the relatively large mesh flounder and groundfish fishery which is conducted in the same general area. The relatively low discard rate of winter flounder can be explained in two ways. First, the minimum legal size of this species is smaller than that of other flounder species, so fewer small individuals are discarded. Second, and probably more importantly, the seasonal migratory behavior and substrate preference of winter flounder is such that few inhabit the deep, muddy substrates typical of the areas where shrimp trawling occurs during the winter months. Studies have shown that large spawning fish tend to migrate from deeper offshore areas to inshore and estuarine areas in the fall, and remain there through the
winter months. As these individuals migrate back to sea in the spring, small pre-recruits (10-20 cm) tend to remain behind in inshore embayments (Perlmutter, 1947; SAILA, 1961; JEFFRIES AND JOHNSON, 1976; OVIATT AND NIXON, 1973). Thus, winter flounder, especially smaller ones, are scarce in deep, offshore areas during the winter, which explains why only about 10 kg were caught per tow in this study, and why of these, only 1.7 kg per tow were too small to be retained for market.

Sizes of winter flounder discards, 17-28 cm, indicates they were from 1-4 years old. Since some become sexually mature at age 3 (Bigelow and Schroeder, 1953), some of the larger individuals discarded may have been sexually mature.

Silver hake

These were the most abundant finfish caught and discarded. Of the 5,149 kg caught, 4,895 kg were discarded because of their small size. The more than 1600 individuals and more than 91 kg discarded in the average tow indicate that this species may be negatively affected by the northern shrimp fishery. Estimates of silver hake discards in other fisheries are scarce. R.K. Mayo et al. (NMFS, unpublished data), estimated that only 0.1% (weight basis) of the silver hake were discarded in the offshore Gulf of Maine trawl fishery, and that none were discarded in other northeast mixed trawl fisheries. Higher estimates were given by Jermyn and Robb (1981) for the North Sea,
where they found that otter trawlers discarded from 10-29% of the silver hake on a weight basis, and from 21-42% on a numerical basis. Discard rates were similar, 14-33% by weight and 23-50% by number, for Danish seiners working in the same area. Estimates for this study are very high relative to these published estimates. It is likely that the relatively small mesh nets used in this fishery simply retain more small individuals, causing discard rates to rise.

The lengths of silver hake discards, 8-31 cm, indicates they ranged from 1-3 years in age (Bigelow and Schroeder, 1953). Since most individuals do not mature until age 3 (Beacham, 1983), it is likely that most of the discards were sexually immature.

Cod were caught in 37 of the 50 tows, and ranked third in weight caught. It is estimated that about 78 individuals and about 25 kg are discarded in the average shrimp tow, and that discard percentages are about 56% by weight and 72% by number. These estimates are very high relative to cod discard estimates from other fisheries in the Gulf of St. Lawrence (Jean, 1963; W.R. Martin and Y. Jean, FRBC, unpublished data) off Newfoundland and Labrador (Kulka, 1985, 1986a,b; Stevenson, 1978), in the Baltic Sea (Jermyn and Robb, 1981; Bagge, 1981), and along the northeast coast of the United States (R.K. Mayo et al., NMFS, unpublished data). In these diverse fisheries, discard estimates range from <1 to 31% by weight and from <1 to 54% by
number. Gear type, area fished, and year all affected discard percentage. The only information available on cod discards in shrimp fisheries are those of Poulsen (1970) and Ulltang and Oynes (1978). During survey work in the North Sea, Poulsen (1970) reported that from 0-5.9 kg of cod were caught and discarded in 30 min tows made with a 1.27 cm codend net. In a similar study off western Greenland, Ulltang and Oynes (1978) found that between 0 and 110 cod were caught per tow (of unreported duration) using a 4.32 cm codend mesh size net. The high discard percentages observed in this study can probably be attributed to the small mesh nets used in the shrimp fishery. It is important to note, however, that among the species studied, the impression was that cod showed the greatest interannual variation in discard amounts. Although sufficient data were not available to make quantitative yearly comparisons, it was noted that relatively few small cod were caught in the first three shrimp seasons, and that many were caught in the 1988-89 season. This may have been due to a relatively strong year-class(es) of cod being encountered by the shrimp trawlers. Examination of the size frequency distribution of discards indicates that most were 20-40 cm long, which corresponds to 1-3 years of age (Bigelow and Schroeder, 1953). If the observations of unusually large numbers of small cod is correct, then discard estimates in this study may be higher than one might expect over a longer time period.
Goosefish

Goosefish were not abundant in the study area. They were present in only 30 of the 50 tows, and only 206 kg were caught. Jean (1965) indicated that goosefish are concentrated at depths $>183$ m during the winter months, and their low abundance in this study may be explained by the relative shallowness (max. 137 m) of our tows. Even though discard percentages were $>41\%$ by weight and 52\% by number, the fact that only about 3.5 individuals and 1 kg were discarded in the average tow indicates that goosefish are not being dramatically affected by the northern shrimp fishery. To my knowledge, there are no other published estimates of goosefish discards.

Significant Variable

Of the independent variables examined, depth was the only one significantly related to discard percentage in any of the species. Neither tow duration nor catch condition were related to percent discard. In an earlier study (Part 1), it was found that both American plaice and witch flounder discard percentages were positively correlated with catch condition. This was interpreted to mean that as the amount of obstructive material (other fishes, invertebrates, rocks, etc.) increased, proportionately fewer small fish were able to escape through the blocked or collapsed codend meshes. In this study, the mean catch condition was 1.6 units on a scale of 1 to 5, and 42 of the 50 tows were assigned values of 2 or less. Thus, most of the tows had little obstructive
material, and no relationship between catch condition and percent discard in any of the species was observed. Tow duration was not related to discard percentage either, suggesting that as the weight of the catch in the codend increases over time, it does not affect the escapement of small fish. Indeed, it seems likely that with the small mesh size used in this fishery, few small fish can escape even when the meshes are fully open.

Discard percentages of witch flounder, silver hake, and American plaice all decreased with increasing depth. In all cases, even though the relationship was significant, it was not strong. Less than 23% of the variation in discard percentage was explained by depth in each case. The linear relationship between depth and discard percentage in witch flounder may be a statistical artifact. Only four tows made <92 m caught this species. In each of these, less than 2.3 kg were caught, and all were discarded. These 100% discard values effectively levered the regression line into a negative slope. When these values were eliminated from the analysis, there was no significant relationship between depth and discard percentage (P>0.05). A similar situation is seen in silver hake. Although some were present in 11 of the 14 tows made in depths <92 m, in each case <4.5 kg were caught, and in only one of these were any of the fish large enough to be landed. Thus, silver hake were quite scarce at the shallower depths, and the few that were present were primarily small. It is possible that the large number of 100% discard values at these shallower depths effectively levered the regression line, much
as it did for witch flounder. Such was not the case for American plaice. Since some were caught in all 50 tows, and since in 48 of these some of the fish were marketable size, the relationship between percent discard and towing depth is valid probably valid. The lower discard percentages seen in deeper water may indicate that larger fish make up a larger proportion of the population at greater depths. Bigelow and Schroeder (1953) have suggested that most American plaice in the Gulf of Maine are found from about 46-183 m, and that larger fish undergo short seasonal migrations, moving into shallow water in the spring for reproduction and returning to deeper water over the winter months. Because this study occurred during the winter, presumably when the larger fish are located in deeper water, it is possible as towing depths increased toward the deeper end of the species distribution, proportionately more of the large fish were encountered. This caused the discard percentages to decrease with increasing depth. The opposite situation, decreased discard percentages with decreasing depth, was reported in Part 1, but, in that instance, most of the tows were made in the spring in relatively shallow water where the larger fish gather for reproduction.

Summary and Conclusion

The discarding of fish is a problem only if some or all of the discarded individuals die and are lost from fisheries directed at them. Jean (1963) found that deck exposure time, air temperature, and fish size all affected the
survival rate of cod and American plaice. For cod <40 cm long, exposed on
deck for <15 minutes, survival ranged from 10-60% when air temperatures
were warm (4.4-7.8 °C) and from 40-78% when air temperatures were cooler
(-1.1-0.6 °C). When deck exposure time was increased to 30 minutes, the
survival rate of the same sized fish decreased. Only 20% survived at the
cooler air temperatures, and none survived at the warmer air temperatures.
A similar pattern was seen for American plaice. Less than 10% of the small
(<30 cm) fish survived after 30 minutes of deck exposure.

The causes of discard mortality are poorly understood, but it is likely
that several variables may be involved. Anatomical damage of trawl-caught
fish can include the rupture of the gas bladder and associated internal trauma
(Rogers et al., 1986), as well as substantial scale loss (Main and Sangster, 1988).
The physiological stresses associated with hyperactivity, which would apply to
trawl-caught fishes, have been documented by Black (1958), Beamish (1966,
1968), Wardle (1972), and Fritz and Johnson (1987). If, as seems likely, the
extent of anatomical damage and/or physiological stress increases with tow
duration, it would explain the observation by Schott (1975) that discard
mortality of small California halibut (Paralichthys californicus) increased
with towing time. Because tows in this study averaged >3 hrs in length, and
because it typically took 30 minutes to an hour to clear the deck, it is likely
that virtually all of the fish discarded in this study were either dead or
moribund. The only exception that was noted were small cod caught in
relatively shallow (<82 m) water. These were quickly discarded by the crews
on all vessels, and appeared to be unharmed.

The large numbers of fish discarded, the presumed high mortality of
these individuals, and the large number of vessels engaged in the northern
shrimp fishery all indicate that this fishery is causing substantial reductions
in abundance and yield of finfish stocks in the Gulf of Maine.

ACKNOWLEDGEMENTS

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Powles, P.M. and A.C. Kohler. 1970. Depth distribution of various stages of witch flounder (*Glyptocephalus cynoglossus*) off Nova Scotia and in the Gulf


Stevenson, S.C. 1981. Summary of discarding and estimates of total removals
by Canadian trawlers during the 1980 Divisions 3LNO American plaice fishery. Northwest Atlantic Fisheries Organization SCR Doc. 81/VI/55.


### TABLE 2-1. Mean (± 2 SE) and range of towing depths (meters) and numbers of tows in each area by month.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean(±2SE) Depth Fish</th>
<th>Range of Depths Fished</th>
<th>Scantum Basin</th>
<th>Ipswich Bay</th>
<th>Jeffreys Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC</td>
<td>123.7 ± 7.3</td>
<td>110-128</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>JAN</td>
<td>100.3 ± 10.2</td>
<td>80-128</td>
<td>5</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>FEB</td>
<td>115.5 ± 9.9</td>
<td>71-137</td>
<td>10</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>MAR</td>
<td>113.1 ± 14.3</td>
<td>91-128</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>
Table 2-2. Disposition of the catch from all 50 shrimp tows.

<table>
<thead>
<tr>
<th>Species</th>
<th>Kilograms Caught</th>
<th>Kilograms Landed</th>
<th>Kilograms Discarded</th>
<th>Percent Discard</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Plaice</td>
<td>2,900</td>
<td>494</td>
<td>2,406</td>
<td>83.0</td>
</tr>
<tr>
<td>Witch Flounder</td>
<td>183</td>
<td>60</td>
<td>124</td>
<td>67.5</td>
</tr>
<tr>
<td>Yellowtail Flounder</td>
<td>156</td>
<td>118</td>
<td>38</td>
<td>24.5</td>
</tr>
<tr>
<td>Winter Flounder</td>
<td>479</td>
<td>395</td>
<td>84</td>
<td>17.6</td>
</tr>
<tr>
<td>Goosefish</td>
<td>206</td>
<td>150</td>
<td>55</td>
<td>26.9</td>
</tr>
<tr>
<td>Silver Hake</td>
<td>5,149</td>
<td>254</td>
<td>4,895</td>
<td>95.1</td>
</tr>
<tr>
<td>Cod</td>
<td>1,973</td>
<td>749</td>
<td>1,224</td>
<td>62.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Kilograms Caught</th>
<th>Kilograms Landed</th>
<th>Kilograms Discarded</th>
<th>Percent Discard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Market Spp.</td>
<td>11,045</td>
<td>2,219</td>
<td>8,827</td>
<td>79.9</td>
</tr>
<tr>
<td>Northern Shrimp</td>
<td>7,764</td>
<td>7,764</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2-3. Weights and numbers of fish landed and discarded per tow and discard percentages averaged over all tows. n = number of tows

<table>
<thead>
<tr>
<th></th>
<th>Mean ± 2 SE</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilograms Shrimp Landed</td>
<td>155 ± 36</td>
<td>50</td>
</tr>
<tr>
<td>Kilograms Fish Landed</td>
<td>74 ± 25</td>
<td>46</td>
</tr>
<tr>
<td>Kilograms Fish Discarded</td>
<td>210 ± 43</td>
<td>46</td>
</tr>
<tr>
<td>Number Fish Landed</td>
<td>142 ± 64</td>
<td>46</td>
</tr>
<tr>
<td>Number Fish Discarded</td>
<td>2,881 ± 658</td>
<td>46</td>
</tr>
<tr>
<td>Percent Fish Discard</td>
<td>67.8 ± 7.8</td>
<td>50</td>
</tr>
<tr>
<td>Percent Fish Discard</td>
<td>93.4 ± 3.2</td>
<td>46</td>
</tr>
</tbody>
</table>

(Weight Basis)

(Weight Basis)
Table 2-4. Mean (± 2 SE) percent discard per tow for the seven species considered in the study.  n = number of tows.

<table>
<thead>
<tr>
<th>Species</th>
<th>Weight Basis</th>
<th>(n)</th>
<th>Numerical Basis</th>
<th>(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Plaice</td>
<td>81.4 ± 4.1</td>
<td>(50)</td>
<td>96.8 ± 0.9</td>
<td>(46)</td>
</tr>
<tr>
<td>Witch Flounder</td>
<td>75.7 ± 10.1</td>
<td>(31)</td>
<td>90.6 ± 5.9</td>
<td>(27)</td>
</tr>
<tr>
<td>Yellowtail Flounder</td>
<td>20.1 ± 9.2</td>
<td>(39)</td>
<td>20.5 ± 11.2</td>
<td>(35)</td>
</tr>
<tr>
<td>Winter Flounder</td>
<td>1.2 ± 5.9</td>
<td>(48)</td>
<td>14.5 ± 7.7</td>
<td>(44)</td>
</tr>
<tr>
<td>Goosefish</td>
<td>41.4 ± 16.5</td>
<td>(30)</td>
<td>52.0 ± 16.6</td>
<td>(30)</td>
</tr>
<tr>
<td>Silver Hake</td>
<td>97.2 ± 4.0</td>
<td>(43)</td>
<td>98.6 ± 1.0</td>
<td>(43)</td>
</tr>
<tr>
<td>Cod</td>
<td>56.2 ± 11.3</td>
<td>(37)</td>
<td>71.2 ± 9.9</td>
<td>(37)</td>
</tr>
</tbody>
</table>
Table 2-5. Mean (± 2 SE) numbers and kilograms discarded in those tows where some individuals of the indicated species were caught (selected tows), and in all 50 tows regardless of presence. n = number of tows used in calculations

<table>
<thead>
<tr>
<th>Species</th>
<th>Numbers</th>
<th>Kilograms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selected Tows (n)</td>
<td>All Tows</td>
</tr>
<tr>
<td>American Plaice</td>
<td>858.3 ± 243.3 (46)</td>
<td>789.6 ± 233.4</td>
</tr>
<tr>
<td>Witch Flounder</td>
<td>30.7 ± 16.0 (27)</td>
<td>16.6 ± 10.9</td>
</tr>
<tr>
<td>Yellowtail Flounder</td>
<td>3.7 ± 2.4 (35)</td>
<td>2.6 ± 2.1</td>
</tr>
<tr>
<td>Winter Flounder</td>
<td>8.1 ± 6.9 (44)</td>
<td>7.1 ± 9.7</td>
</tr>
<tr>
<td>Goosefish</td>
<td>5.9 ± 3.0 (30)</td>
<td>3.5 ± 2.0</td>
</tr>
<tr>
<td>Silver Hake</td>
<td>1907.4 ± 733.0 (43)</td>
<td>1640 ± 657.4</td>
</tr>
<tr>
<td>Cod</td>
<td>105.1 ± 47.0 (37)</td>
<td>77.8 ± 37.0</td>
</tr>
</tbody>
</table>

75
TABLE 2-6. Results of functional linear regression analyses.  
Square-root-arcsine percent discard (weight basis) = dependent variable (X), and depth (fathoms) = independent variable (Y).  \( R^2 \) = coefficient of determination, F = significance test of regression, and t tests the hypothesis that slope = 0.  * = P<0.05, ** = P<0.01, *** = P<0.001.

<table>
<thead>
<tr>
<th></th>
<th>X Intercept</th>
<th>Slope</th>
<th>R²</th>
<th>t</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Plaice</td>
<td>136.5</td>
<td>-1.2</td>
<td>22.8</td>
<td>-3.8***</td>
<td>14.2***</td>
</tr>
<tr>
<td>Witch Flounder</td>
<td>263.9</td>
<td>-3.1</td>
<td>22.6</td>
<td>-2.9**</td>
<td>8.4**</td>
</tr>
<tr>
<td>Yellowtail Flounder</td>
<td>155.2</td>
<td>-2.3</td>
<td>1.5</td>
<td>-0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Winter Flounder</td>
<td>117.3</td>
<td>-1.8</td>
<td>5.4</td>
<td>-1.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Goosefish</td>
<td>295.6</td>
<td>-4.1</td>
<td>0.0</td>
<td>-0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Silver Hake</td>
<td>155.6</td>
<td>-1.2</td>
<td>11.3</td>
<td>-2.3*</td>
<td>5.2*</td>
</tr>
<tr>
<td>Cod</td>
<td>187.0</td>
<td>-2.3</td>
<td>0.0</td>
<td>-1.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Figure 2-1. Areas fished in the Gulf of Maine.
Figure 2-2. Length frequency distributions of discarded American plaice and witch flounder.
Figure 2-3. Length frequency distributions of discarded cod and silver hake.
PART 3. GEAR MODIFICATIONS AND REGULATIONS ASSOCIATED WITH BYCATCH AND DISCARDS IN TRAWL FISHERIES
ABSTRACT

Increased effort in the Northern shrimp fishery, in addition to documentation of the adverse effects of small mesh trawls on some finfish stocks, has prompted interest the development of more selective fishing gear. Studies of fish behavior during the trawling process using underwater video have provided information that has been extremely useful for the design of selective trawls. In this paper, fish behavior, trawl modifications, particularly those intended to separate finfish from shrimp, and regulations aimed at reducing finfish bycatch are discussed.
GEAR MODIFICATIONS

Following the implementation of the Fisheries Conservation Management Act, also known as the Magnuson Act, in 1976, stocks of principal groundfish and flounders began to recover from the intense foreign fishing pressure of the 1960's and early 1970's. The increased abundance of fish was quickly recognized and exploited by the industry and the foreign fishing effort was replaced by a rapid increase in domestic fishing pressure. The result was that by the early 1980's, landings and catch per unit effort began to decline (NMFS, 1991). Increasing demand for seafood products boosted prices paid to the fishermen and partially countered the economic hardship of declining landings, however the fishing fleet had to travel farther offshore to find fish. Smaller, dayfishing trawlers that lacked the ability to travel more than a few hours from their home port were impacted most heavily, since the nearshore stocks of groundfish were the first to decline. These vessels began to rely more heavily on winter shrimp fishing, and effort in the northern shrimp fishery increased from 1,100 annual trips in 1980 to a high of 12,300 trips in 1987. Shrimp fishing effort remained relatively constant from 1988-1990 at about 9,400 trips per year (NMFS, 1991). With the decline in landings in the groundfish fishery, the increased effort for northern shrimp, and the alarming numbers of discards associated with the
In the shrimp fishery, it became apparent that efforts must be made to reduce the bycatch through either regulating effort or modifying the fishing gear.

Studies regarding the behavior of fish in response to trawls (Glass and Wardle, 1989; Main and Sangster, 1981; Wardle, 1983, 1986a, 1986b, 1988; Watson, 1988) have indicated that trawl selectivity is influenced by much more than mesh size. Observations of fish and shrimp behavior made using SCUBA, remote cameras, and ROV's indicate that there are significant differences in the behavior of different species and different sizes of the same species. The reaction of a fish to an approaching trawl is a response to stimuli produced by different parts of the trawl, and can vary with environmental conditions. Since fish react primarily to visual stimuli (Wardle, 1986b), their behavior can be altered by light level, water clarity, and contrast (color) of the trawl components. Fish also react to tactile stimuli, sound, and changes in water flow characteristics within the trawl (Watson, 1988). In addition, fishing practices such as the type of ground gear on the sweep, rise of the trawl, and towing speed can influence the behavior of fish and their ability to avoid capture. Behavioral studies such as these indicated that it was possible to design trawl modifications that would increase the selectivity of the gear.

Attempts to reduce bycatch and discards in the U.S. northern shrimp fishery through gear modification began in the mid-1980's with support from Maine/NH Sea Grant and Maine Department of Marine Resources. One of the simplest modifications was the use of sections of large-mesh (30.48 cm)
twine sewn into the belly (bottom) of the shrimp trawl immediately behind the footrope. It was touted by Maine fishermen as a good flounder bycatch reduction strategy and was used voluntarily by a number of Maine trawlers. Escape from this area of a trawl by flounders was not observed in earlier studies in Europe (Main and Sangster, 1981), and during field trials conducted off the New Hampshire Coast in 1986 (R. Barnaby, personal communication), the expected reduction in flounder bycatch using large mesh in the lower section was not documented. Main and Sangster (1981) made observations of the behavior of several species of flounder to approaching trawls using underwater video. Although they observed some flounder escaping under the ground gear (footrope), most were observed dropping back into the net after swimming in front of the trawl for no more than 60 seconds. None were observed attempting to escape through the meshes in the bottom panel of the net. Behavioral responses of cod, haddock, pollock, and silver hake indicate that this modification would not be effective for releasing roundfish species either. These species were observed to avoid the lower panel of a towed trawl, and when they began to tire either swam upward (haddock, pollock, and some silver hake), or turned and dropped back into the net a short distance above the lower panel (cod and some silver hake) (Wardle, 1986a; 1986b; 1988, Main and Sangster, 1981). Several trawl designs adapted from European fisheries were also tested. The use of a sloping separator/excluder panel sewn horizontally across the extension piece of the
net was used in two different separator trawl designs. The efficacy of this technique for separating shrimp and fish has been supported by video observations made by Main and Sangster (1981) and Wardle (1988) and has been used to separate haddock from *Nephrops* (Norway lobster) in European trawl fisheries (Wardle, 1988). One type of design that was tested consisted of an escape panel (either very large mesh or a "flapper") at the top of the extension. The theory was that fish actively position themselves higher in the net than shrimp, are deflected by the separator panel into the upper half of the extension, and because of their greater swimming ability and the visual stimulus of the opening, are able to escape from the trawl. The shrimp which are positioned lower in the net, under the separator panel, are swept into the cod end. Another design that employed the separator panel consisted of the divided extension piece followed by two separate cod ends, one over the other. This net design, also called the trouser trawl, could be used with large mesh in the upper cod end, or the upper cod end open to allow all finfish to escape (Wardle, 1988). Difficulties were experienced with the separator trawl designs even before their effectiveness as bycatch reduction devices could be determined. In early experiments it was found that the separator panel did not always divide the net as planned, and required the use of floats to keep it in position. Many small fish became gilled in the separator panels and reduced the effectiveness of the design (Watson, 1988). Also, addition of the panel altered the original trawl design and made net construction difficult,
and repair very complicated and time consuming for fishermen, especially at sea. Much time and money was spent on designing and building separator trawls and the results of field trials were disappointing. Neither design eliminated the bycatch of flounders, and the bycatch data for other species showed no significant differences between separator and standard shrimp trawls during early field trials (Griffin, 1990; Watson 1988). In addition, fishermen complained that they would not only lose the incidental catch of valuable groundfish, but an unacceptable portion of the shrimp catch would be lost as well.

Another design employed the use of either one or two accelerator funnels sewn into the extension piece and followed by either; (1) an open area where the cod end is actually separated from the extension and the connection between the two pieces is made using ropes; or (2) a section of large mesh twine (either diamond or square), or a "flapper" type escape panel in the upper part of the extension, similar to that which was used in the separator trawl (Fig. 3-1). The theory of this design was that the fish and shrimp would increase their speed toward the cod end of the net due to water currents generated by the funnel, and that the shrimp, because of their lack of swimming ability, would tumble into the cod end, while the fish, reacting to the relatively calm water behind the funnel, would swim out of the net through the escape panels (Watson, 1988). Field trials of these designs also indicated that bycatch was not significantly reduced and that a substantial
portion of the shrimp catch was lost (Griffin, 1990).

In 1986, Dr. Hunt Howell and I tested a mid-water shrimp trawl on a commercial vessel out of Portsmouth, N.H. Fishing for northern shrimp in the Gulf of Maine has always been a daytime fishery. Meager catches of shrimp in tows made by fishermen after sunset indicated that the shrimp migrate up off the bottom at night. We felt that if night fishing for shrimp with a off-bottom trawl was successful, the bycatch of demersal fish species, particularly flounders, could be eliminated. A small grant was obtained from N.H. Sea Grant Development to pursue the project. We borrowed a mid-water shrimp trawl, designed and built several years previously but never used, from Cliff Goudy, a fisheries technologist from MIT, and solicited the cooperation of Ramon Levesque, Captain of the commercial fishing trawler F/V Julie and Jill. The trawl consisted of a rigid rectangular frame, 18' x 30', constructed of aluminum sailboat spars, a maze of towing bridles and a small, four panel net. After simplifying the towing bridle arrangement and adding an extension and cod end (under Captain Levesque's guidance), we field tested the net on four occasions. Because of the large rigid frame, the net was difficult to transport and handle onboard and much time was spent mending tears in the twine before we even got it overboard. The towing depth was determined by the angle of the main trawl wires and the length of wire deployed. We tried to match the towing depth with what we believed were echosounder traces of shrimp in the water column, and towed the net at
those depths anywhere from 0.5 to 2 hours. Each time the net was hauled on board it was completely empty. We made several adjustments to the bridles, added floats to be sure it was positioned properly in the water, but were never able to catch anything at all. Sometime during what was to be our last tow with the mid-water trawl, one of the aluminum spars was bent beyond repair and the project was abandoned.

The most promising gear modification for bycatch reduction was developed in Norway in 1989. Most of the separator trawls described previously were originally designed for the Norwegian pandalid shrimp fishery, which has been operating under strict bycatch regulations since the early 1980's. The Norwegians found, as we later did, that most of these earlier designs were ineffective. In 1989, several experiments were conducted with a rigid grate, originally developed to exclude jellyfish, sewn into the extension piece at an upward sloping angle. It’s separating characteristics were promising and research efforts aimed at shrimp retention and fish separation were initiated. A number of investigations were conducted, using different materials, dimensions, and angle of placement of the grate, and different flapper and funnel designs. The results were so successful that the final design, called the Nordmore grate (Fig. 3-2), was made mandatory in Norway's north coast pandalid shrimp fishery in March of 1990, and was accepted without much protest from the fishing industry (Blott, 1991).

The second round of experiments with the Nordmore grate was
conducted in Maritime Canada, where a 10% bycatch restriction has seriously curtailed the shrimp harvest. In 1990 the Canadian Department of Fisheries and Oceans (DFO) conducted two experiments with the Nordmore grate. Using a trouser trawl divided into right and left cod ends with a vertical divider (rather than top and bottom cod ends described previously), the grate was installed ahead of one cod end while the other was used as a control. A DFO research vessel made 28 tows with the trawl and 21 tows were made by a commercial vessel. Both experiments confirmed that the grate is an effective separator. Bycatch was reduced by the grate from 47% to 4.2% on the research vessel and from 39% to 1.7% on the commercial vessel. Shrimp catch was 2% less and 10% greater respectively with the grate (Blott, 1991). The grate is now mandatory for vessels in the Scotia-Fundy region while vessels from other areas can fish without it provided they carry an observer and do not exceed the 10% bycatch limit.

Additional experiments with the Nordmore grate were conducted in the U.S. The Atlantic States Marine Fisheries Commission (ASMFC) and the New England Fisheries Management Council (NEFMC) were reluctant to impose mandatory use of the Nordmore grate on New England fishermen until they had more data on its effectiveness. At the Council's request, the Conservation Engineering Section of the National Marine Fisheries Service tested the grate in the spring of 1991. The first experiment consisted of video documentation of the operation of the grate. As the trawl was towed in
depths ranging from 10 to 50 fathoms, shrimp and small fish were observed passing through the grate into the cod end while larger fish and some shrimp passed out through the fish outlet. Lobsters and some fish such as skates were observed resting on the aluminum grate before sliding up and out. The second experiment consisted of 13 paired, one hour tows made in the Sagadahoc area in depths ranging from 85 to 95 fathoms. The results were very favorable. The grate reduced bycatch from 220% to 38.3% and shrimp catch increased by almost 30% (Blott, 1991). Several problems with the grate that were encountered during the experiments indicate that it will require additional work before New England fishermen find it acceptable. Concerns that twists will develop in the extension piece in front of the grate, that it is not flexible enough to go onto a net reel, and that shrimp and valuable finfish will be lost, were expressed by commercial fishermen involved with the experiments. The Conservation Engineering Section responded to the first two concerns by substituting the aluminum grate with one constructed of high molecular weight polyethylene. The reduced weight and positive bouyancy of the polyethylene eliminated the need for additional floatation and allowed any twists in the extension piece to come out when the net was towed. The poly grate is much more flexible and resiliant and therefore expected to better withstand the rigors of net reel use. The NEFMC and NMFS plan to continue refinement of the Nordmore grate and it's use will be mandatory during April and May of the 1992 shrimping season.
Similar bycatch problems in the penaeid shrimp fisheries in the Southeastern Atlantic and Gulf states have prompted the development of trawl designs that have become known as bycatch reduction devices, or BRDs. Although both the shrimp, and the finfish that constitute the bycatch are different species than in the New England fishery, gear modifications in the southern states fishery deserve mention here. The first such gear modification to be implemented was the TED, or turtle exclusion device, designed to reduce the catch of sea turtles. Though fishermen resisted the mandatory use of TEDs, and complained of large reductions in the shrimp catch, they were found to be effective in reducing the turtle catch by 97% (Rulifson et al. 1992). During TED development, SCUBA observations led to design modifications to reduce catches of finfish, jellyfish, skates, rays and sharks (West et al., 1984; Watson et al., 1986). Though the designs are different (Fig. 3-3), the same general separation and exclusion principles as in the Nordmore grate are applied in the southern BRDs. Three different trawl modifications (BRDs) were tested in paired tows with a standard shrimp trawl (Rulifson et al., 1992). They found that the relative effectiveness of the different designs was species specific, and that no one design produced the desired results of 50% bycatch reduction and less than 5% shrimp loss. The results were sufficiently favorable, however, to encourage further research into reducing bycatch while maintaining shrimp catching efficiency.

Although the discard problem in the New England groundfish fishery
is not nearly as serious as in the northern shrimp fishery, some mention should be made in this section regarding gear modifications to groundfish trawls. Minimum codend mesh size, which has been set since 1976 by the NEFMC, has been periodically increased to its current 13.97 cm size. Consideration of an increase to 15.24 cm mesh is a current topic of discussion proposed for amendment 5 to the reauthorization of the Magnuson Act. An article published in "Commercial Fisheries News" (Jones, 1991) constructed a table comparing the size and age of first spawning for principle New England groundfish and flounders that are retained by 13.97, 15.34, and 15.88 cm diamond mesh. Though the table was constructed using data from three different sources, and the numbers used for 15.88 cm mesh are theoretical, therefore compromising its credibility, it does provide some interesting information on the biological justification for minimum mesh size. The table indicates that 13.97 mesh captures all principle groundfish and flounders except redfish, a minimum of 12 months before first spawning, and that 15.34 mesh would only add winter and yellowtail flounder to the list of exceptions. The article implies that the 13.97 cm mesh regulation is not an effective management tool because it exposes too many fish to capture before first spawning. A thorough analysis of the effect of 15.34 cm codend mesh resulted from disagreements between industry representatives and federal fisheries scientists over the measures necessary to reduce the overfished condition of cod and yellowtail flounder. NMFS has determined that
recovery of cod and yellowtail stocks will require that Spawning Stock Biomass (SSB) be increased to 20% of Maximum Spawning Potential (MSP).

Spawning Stock Biomass/Recruit (SSB/R) analyses conducted by the Plan Development Team (PDT) of the New England Fisheries Management Council (NEFMC) determined that at the current level of fishing (F), the increase in mesh size is not expected to achieve the 20% MSP (NEFMC, 1992a) and that reduction in fishing effort will be required. Representatives of the fishing industry, faced with the possibility of effort controls, retained the services of outside consultants to dispute the PDT’s findings. Studies conducted by Canadian Fisheries Consultants Limited (1992) and the Rothschild Ault Group concluded that 15.34 cm mesh would result in the target %MSP (NEFMC, 1992b). The models used in all three studies are highly sensitive to small changes to input parameters such as natural mortality (M), size and age at first spawning, median spawning time, and length and weight at age. The Science and Statistical Committee (SSC) reviewed the three reports and supported the position of the PDT; that measures beyond increased mesh size would be required to rebuild cod and yellowtail stocks.

Mesh configuration as well as mesh size may also affect escapement and minimize damage to juvenile fish. Wardle (1988) observed that by the time small fish reach the cod end of a trawl, especially one that is partially full, they are already exhausted and have great difficulty wriggling out of stretched and tightened meshes. He felt that in order for small fish to escape
at late stages of the capture process, the mechanics of the cod end should be reconsidered so that the fish are presented with the largest possible area of open meshes. One such configuration is the use of square mesh cod ends. Experiments that compared standard diamond mesh cod ends to equal size square mesh cod ends, indicate that escapement and survival is greatly improved for roundfish species such as cod and scup when square mesh is used. Preliminary findings indicate that square meshes do not improve escapement of juvenile flatfish. Underwater video observations of flatfish behavior in otter trawls (Main and Sangster, 1981) indicated that once they reached the cod end, they were too exhausted to swim, and most were hard pressed against the twine. Many Canadian fishermen, particularly from Nova Scotia and Newfoundland are cod fishing consistently with square mesh and report that it has reduced the catch of juveniles to levels acceptable to Canadian authorities (Lazarus, 1989).

A Norwegian excluder device for releasing undersized, juvenile fish from groundfish trawls was tested in 1991 in Norway and Iceland. The device, called a Trollex, which was developed by Roger Larsen of the Norwegian College of Fishery Science, in cooperation with other researchers, fishermen, and the Norwegian fishing gear firm, NOFI, is said to be suitable for any trawl fishery. The Trollex consists of a metal grid, fitted with floats and positioned in the extension piece immediately forward of a standard cod end. The grid is angled so that small fish can exit the trawl by passing
through the bars of the grate after which they are directed away from the trawl by the Trollex's aft section, a framework covered with canvas. Large fish cannot pass between the bars and continue into the cod end. Field tests have shown that 91% to 96% of all cod less than 48.26 cm and 96% to 100% of all haddock less than 44.45 cm are released through the grid. The Trollex has gained acceptance with Norwegian fishermen, even though it cannot be wound onto the net reel. The Trollex is currently being tested in Canada's East Coast cod and redfish fisheries (Wray, 1991).

The entire U.S. fishing industry is under a great deal of pressure from the NMFS and environmental groups to address the bycatch issue. Continued support of conservation engineering and further understanding of fish behavior in trawls may perhaps lead to the development of more selective, effective trawls.
REGULATIONS

Discarding has been recognized by fisheries managers as a major problem in trawl fisheries. Because of the effects discarding can have on recruitment potential, biomass, and yield, it is imperative that regulations aimed at discard reduction be implemented. Regulation of the northern shrimp fishery is under the jurisdiction of the Atlantic States Marine Fisheries Commission which reviews shrimp stock assessment data generated by NMFS, and sets the length of the season. Recent regulations have been aimed at reduction of discards. In the 1989-1990 and 1990-1991 shrimp seasons, boats fishing during April and May were required to use an approved separator trawl (Fig. 3-1). In addition, bycatch of landed groundfish was limited to 25% of the total shrimp catch. For 1991-1992, the ASMFC considered mandatory use of the Nordmore grate for the second half of the shrimp season, March through May. The Commission, however, decided to gather more experimental data on the grate, and to mandate its use for boats fishing in April and May. The 25% groundfish bycatch was maintained, and the season was shortened by 15 days in December, 15 days in May, with no shrimping allowed on Sundays during the 1991-1992 season.

The groundfish fishery is regulated by the New England Fisheries Management Council (NEFMC), one of the regional councils created by the
Magnuson Act (FCMA) in 1976. The discard problem has been addressed by 
implementing minimum mesh sizes, and minimum lengths for cod, 
haddock, pollock and flounders, and areas closed to small mesh fisheries. 
Current minimum mesh size is 13.97, though that may soon change. The 
NEFMC is currently under fire for failure to prevent the overfished condition 
of groundfish stocks in the Northeast. A consent decree (a court order 
resulting from a lawsuit filed by the Conservation Law Foundation and the 
Massachusetts Audubon Society against the Department of Commerce), has 
ordered that the Council draft a groundfish stock rebuilding plan by March 
1992, and to submit a final plan by September 1, 1992. Among the measures 
that the Council is expected to approve is a increase of the minimum mesh 
size to 15.24 cm and a 10% reduction in fishing effort. The NEFMC has 
experienced a certain amount of frustration when dealing with the problem 
of discards, since the shrimp fishery, in which discards are substantial, is not 
within their management jurisdiction.

Reauthorization of the Magnuson Act will undoubtedly include 
several amendments that will substantially reduce fishing effort in the 
Northeast. Efforts should be made as well to insure that our fisheries are 
more selective and that discarding be reduced as much as possible. It would 
be advantageous to include in these amendments, provisions to support 
programs focussed on conservation engineering and fish behavior studies 
involving both research and industry, and to provide a mechanism for
immediate technology transfer to the fishing industry.

It has become quite obvious that without radical changes in fishing practices, groundfish stocks will continue to decline and may perhaps reach the point of no return. This would of course result in total collapse of the highly capitalized trawl fisheries in the Northeast and a serious economic setback for coastal communities. Having been asked to outline what I would consider to be an ideal set of regulations for the New England trawl fisheries, I was initially somewhat reluctant to do so. Because this is a dissertation, however, I realize that any regulations I may come up with will not affect the livelihood of an entire industry. In that context, I propose the following:

1. A five year moratorium on new entrants into the groundfish and shrimp fisheries.
2. Minimum cod end mesh size of 15.34 cm for the groundfish fishery.
3. 10% reduction in the number of days participating in trawl fishing for each vessel currently holding a permit. Total days will be based on an average number of days fished per year over the last five years. The 10% reduction will continue each year for five years, and undergo reevaluation and adjustment each year. Vessels will be permitted to fish on the days they are prevented from trawling, but they must use longline gear. Low interest loans will be provided through NMFS for vessel owners to purchase longline gear, and workshops and training sessions will be provided by NMFS.

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4. Maintain current spawning closure areas.

5. Mandatory use of the Nordmore Grate or any type of separator gear that will reduce bycatch by > 75%. Vessel owners will be given low interest loans to purchase separator gear. Loans are to be repaid within two years. Shrimp season shall begin December 1 and end March 31. Areas that are determined to be nursery grounds will be closed to shrimping.

6. Any violation of minimum mesh regulation (#2), exceeding allowable days trawling (#3), shrimping either without separator gear (#5), or with separator gear that has been altered will result in immediate and permanent revocation of the vessel's (and/or) captain's permit.

7. Minimum sizes for fish shall be as follows:

   Cod and pollock, 53 cm; haddock, 48 cm; American plaice, witch flounder, and yellowtail flounder, 36 cm; winter flounder, 31 cm. Possession of > 5% of undersized fish (by species, by weight) will result in revocation of fishing permit. Possession of > 5% (by species, by number) of undersized fish by any processing facility shall result in a fine of $1,000 per fish.

8. The NMFS shall commit $3 million of its annual budget for each of the next five years to study fish behavior during fishing operations and to develop more selective fishing methods. All research will include industry, government, and technical (private or academic) components, and all data will be public information. NMFS may at any point mandate the use of any fishing technology if it has been proven to significantly improve selectivity.
Provisions shall be made for permit holders to acquire low interest loans to purchase any mandated fishing gear.
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Figure 3-1. Diagram of a shrimp/fish separator. This is one of several separator designs approved for use in the 1989-1990 and 1990-1991 shrimp seasons in the Gulf of Maine. Diagram from National Fisherman, May 1990. Vol. 71, No. 1.
Figure 3-2. The Nordmore Grate System for separation of finfish and shrimp. Diagram from Commercial Fisheries News, October 1991.
Figure 3-3. Three types of Bycatch Reduction Devices (BRD's) tested off the coast of Georgia in 1990. Diagram from Rulifson et al., 1992. Fisheries, Vol. 17, No. 1.
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