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Discarding in the Small-Mesh Fisheries of the Mid-Atlantic Bight

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Abstract

The small-mesh fisheries of the Mid-Atlantic Bight (particularly *Loligo* squid, butterfish, and silver hake) may be important discarding sources for many commercially and recreationally-important species. The NMFS-NEFSC† observer database for 1997 to early 2002 augmented by independent observations was analyzed to evaluate the importance of discarding in these fisheries in the Mid-Atlantic region. Ten target species-discard species pairs were identified in which the volume of discards was significant: silver hake, *Illex* squid, and butterfish in the *Loligo* fishery; spiny dogfish, silver hake, butterfish, and summer flounder in the silver hake fishery; and weakfish, spiny dogfish, and butterfish in the butterfish fishery. These discarded species were characterized by high discarding volume in the targeted fishery in comparison to other targeted fisheries, high discarding volume in comparison to all discarded species in the targeted fishery, and high discarding volume in comparison to the landings volume of the same species. Market considerations accounted for the vast majority of discards in the 10 target species-discard species pairs. Regulatory discarding does not appear to be an important component of discarding in the small-mesh fisheries, except for scup. With the exception of spiny dogfish and butterfish discarded in butterfish-targeted tows, all discard-to-target species landings ratios were low; in most cases well below 0.2. Thus, target species volume is the primary generator of high total discard volume, rather than high per-tow catch and discard rates. Low per-tow discarding rates minimize the effectiveness of most discard-reduction approaches, except gear improvements, unless discarding

† National Marine Fisheries Service – Northeast Fisheries Science Center.

is predictably distributed in time or space. *En masse*, the analyses suggest that space and time options for discard reduction are few and unlikely to be successful, because the pattern of discarding is stable only over short time and space scales. The obvious approach to managing discards in the small-mesh fisheries is to more rigorously evaluate codend mesh sizes that might effect a reduction in the catch of undersized individuals. An exception is spiny dogfish, for which discarding events are frequent and discarding is high. A more detailed evaluation of spiny dogfish discards in the small-mesh fisheries, particularly butterfish, is clearly warranted. Discarding has increased in *Loligo* squid-targeted tows for a number of species despite efforts to reduce scup discarding through area-time closures. The institution of area-time closures to control discarding should be evaluated for the likelihood that differential effort distribution necessitated thereby may exacerbate discarding elsewhere.

Introduction

Fishing activities routinely result in the entrapment of non-target species. In some cases, these individuals are landed under regulations permitting the taking of defined quantities of non-target commercial species. In other cases, because the individuals are not marketable or because regulation prohibits their landing, individuals are discarded. Although exceptions exist, normally, discarded individuals are assumed to suffer 80-100% mortality (e.g., NEFSC, 2000). Accordingly, discarding typically counts against total allowable catch when annual quotas are established.

The small-mesh fisheries of the Mid-Atlantic Bight, particularly *Loligo* squid, butterfish, and silver hake, pose potential difficulties for management because the small mesh size used potentially enhances the discard of non-target commercially and recreationally-important species (NEFSC, 2000; Kennelly, 1999; Glass et al., 1999). Under certain scenarios, discarding in the small-mesh fisheries could account for a substantial fraction of the yearly total allowable catch of other regulated species. One such species that has come under scrutiny is scup, *Stenotomus chrysops* (NEFSC, 2000). Legal mesh size for scup is 11.4 cm in comparison to the 6.35 cm and smaller meshes used in the small-mesh fisheries. As a consequence, discarding of scup in the small-mesh fisheries has received considerable attention in the management process (e.g., Anonymous, 2003, Stevens, 2003). Regulations restricting the small-mesh fisheries to certain times and locations to achieve a significant bycatch reduction of scup have been imposed and these regulations

have generated some controversy. Recent analyses, however, have indicated that scup discarding in the small-mesh fisheries is not a significant source of scup mortality. The directed scup fishery is principally responsible (Powell et al., submitted a). This does not obviate the more general concern about discarding in the small-mesh fisheries, however. Other commercially and recreationally-important species are caught and discarded in these fisheries and these discards may be significant in the total yearly mortality of these species. In addition, the small-mesh species represent important prey species for many commercially and recreationally important piscivores (Overholtz et al., 2000; Buckel et al., 1999).

The purpose of this study is to evaluate the small-mesh fisheries in the Mid-Atlantic Bight as principal sources of discarding of other commercially and recreationally-important species; to identify the reasons for these discards, whether environmental, regulatory, or fishing practice-dependent; and to suggest possible options for effectively reducing discarding of species for which discarding in the small-mesh fisheries is a significant fraction of fishing mortality during the year.

Methods

Description of data

Limiting conditions – Database

The data used in this study were obtained from the NMFS-NEFSC observer program during 1997 to early 2002 augmented by data obtained by Bochenek et al. (submitted). The year 1997 was chosen because the most recent mesh size regulations in a number of fisheries were imposed at this time. Methods used in data collection are described in NEFSC (2002b). We utilized data for all recorded species landed and discarded by trawl or dredge, with the following exceptions. First, for some tows, the observer recorded that part or all of the catch was released overboard. Usually, some discard estimates are given for some species caught on these tows. However, the quality of these discard estimates is questionable because the catch was not fully brought onboard and accurately weighed. As a consequence, these tows were deleted from the analysis. Second, for a number of tows, landings were recorded without discards. Perusal of written notes by the observers indicates that many such tows occurred while the observer was asleep or when sea conditions were too dangerous to work up the tow. Regardless of whether a reason was given, we deleted these tows, assuming that some discards must exist in all completely

analyzed tows, so that inclusion of tows with no discards would likely bias low subsequent discard estimates. Third, we only included observed sea scallop dredge hauls south and west of Block Island. For some species, discard estimates in the sea scallop fishery will be underestimated.

Limiting conditions – Assignment to Fishery

Observed tows must be assigned to a directed fishery. One approach is the *a posteriori* assignment based on the catch. Tows might be assigned according to the species with the largest landings for the tow, for example. An *a posteriori* assignment was not utilized in this analysis for two reasons. First, the *a posteriori* approach inherently restricts application of the analysis in fisheries management because it does not assign tows based on fishing practice whereas regulations permit and control fishing practices. Discard analysis must be conducted on the same basis as discard management. Second, the analysis will necessarily delete some tows from certain directed fisheries where the Captain sought but failed to succeed in obtaining a desired catch. An alternative, less desired, species might then be allocated this tow, but the tow would be regulated under the desired species. Such tows may produce large discards and hence the *a posterior* approach will likely bias low the final discard estimate. The alternative is to utilize the Captains' *a priori* declarations of target species. The Captain is asked to declare the target species for each tow and presumably this declaration is based on the regulated fishing practice the Captain intends to use during the tow. This *a priori* approach permits analysis based on the necessary underlying principal that fishing practice should dictate analysis as well as regulation. However, use of target species declarations interposes its own conundrums that must be resolved.

Target species were sometimes ambiguously declared by the Captains. Ambiguous target-species designations of 'unknown flounder', 'unknown skate', 'unknown squid', and 'unknown groundfish' were most common. In order to retain as much data as possible, tows with ambiguous target species were perused and assigned to discrete target species in the following manner. In some cases, only a single species of the group indicated, e.g., unknown flounder, groundfish, squid, or skate, was routinely caught during the tow. That species was assigned as the target species. In other cases, more than one species that fit the target category was caught. Frequently, for example, two flounder species were caught in tows with 'unknown flounder' listed as the target species. In these cases, more than one target species was

designated. As a general rule, target species were designated because they were representatives of the declared species group, they were consistently caught in most tows, and the average landings exceeded 45 kg tow^{-1}. In some cases, the species caught and reported as landed was also listed under an unknown designation (e.g., 'unknown squid'). In this case, the 'unknown target' designation was retained for further analysis.

The declaration of multiple target species occurred more commonly after 2000. Prior to 2000, the NMFS-NEFSC observer database provided only a single field for target species. Some common multiple targets were included by dual designation in the same field (e.g., silver hake/squid). In contrast, after 2000, a maximum of five fields was provided for target species. As a result, a significantly increased incidence of multiple-target declarations exists after 2000. One goal of the present analysis is to estimate total discarding by target species. Including tows with multiple species targets would result in some discards being counted more than once, if all discards in a tow were assigned to all target species. Accordingly, all discards in these tows were distributed in equivalent proportions to all target species. For example, if butterfish and *Loligo* squid were designated targets for a tow, then half of the butterfish discards on that tow were assigned to butterfish-targeted tows and half to *Loligo* squid-targeted tows. Realistically, however, some of the multiply-declared target species might be secondary targets on any given tow. Powell et al. (submitted a) address one such case for black sea bass-scup dual designations. For such tows, then, the proportional distribution of discards to all declared target species would tend to bias high the discards assigned to secondary targets. Multiply-declared targets were not prioritized in this study. Of equivalent significance for this study is the increase in frequency of declared or inferred multiple targets after 2000 that also might introduce a bias in the assignment of discards to target species; thus compromising comparability across years.

All three potential biases introduced by using *a priori* target declarations, namely ambiguous targets, multiple targets, and a time-dependency in the number of multiple targets, are considered explicitly in the forthcoming statistical analyses.

Calculation of Total Fisheries Discards

To estimate the fractional contribution of each target species to the total discards of any species, we used landings data for 2001 for each target species. Perforce, unknown or ambiguously-designated target species were deleted from

this analysis. In addition, landings data were not available for little skate and winter skate, so discards in these fisheries were not considered. Of greater potential significance, we also deleted all target species with fewer than 5 trips and 10 tows from the analysis because the dataset was unlikely to be representative of the fishery as a whole.

Landings of target species accrue from targeted tows and as bycatch from tows of other target species. The distinction is not maintained in the landings database. Thus, simply taking the discard-to-landings ratio from the targeted tows in the observer database and applying them to the landings data for each target species introduces a bias that normally would result in multiply counting some discards. Total discard estimates would then be biased high. Consequently, we first apportioned reported landings into targeted and landed bycatch categories for each target species by estimation. To do this, we calculated the landed bycatch-to-target species landings ratios for each landed species also represented by a targeted fishery. In the case of the target species, this ratio is 1.0. These ratios were then used to predict the volume of landings assigned to each species landed by each targeted fishery:

$$estimated\,landings_{ij} = \frac{bycatch\,species\,landings_{o_{ij}}}{target\,species\,landings_{o_j}} * reported\,landings_j, \quad (1)$$

where i stands for the ith species landed in tows from the jth targeted species, and o indicates estimates obtained from observed tows. The set of all estimated landings, each in the form of equation (1), is a set of linear algebraic equations of the form:

$$a_{i,1}x_1 + a_{i,2}x_2 + a_{i,3}x_3 + ... + a_{ij}x_j = b_i \quad (2)$$

where a_{ij} is the landed bycatch species-to-landed target species ratio, the first term on the right-hand side of equation (1), x_j is the landings of target species j, the second term on the right-hand side of equation (1), and b_i is the total reported landings for species i or the sum of targeted and bycatch landings. The set of linear algebraic equations summarized by equation (2) was solved by Gauss-Jordan elimination (Press et al., 1989).

Discards were estimated by applying the discard-to-target species landings ratio to the estimated landings of target species in targeted tows:

$$estimated\,total\,discards_i = \frac{discards_{o_i}}{landings_{o_j}} * estimated\,total\,target\;landings_j. \quad (3)$$

This simple method of apportioning landings is based on the assumption that the landed bycatch species-to-landed target species ratios from the observer data

[first term, right-hand side of equation (1)] are a reasonable representation of the true landed bycatch species-to-landed target species ratios. We cannot evaluate the accuracy of this assumption. We tested the degree to which our apportionment into bycatch and target landings might provide erroneous discard estimates by recalculating the landed species-to-landed target species ratios from the predicted landings and comparing these ratios to the original ratios in the database. The vast majority of cases where the observed and predicted ratios differed substantially occurred in American plaice, witch flounder, American lobster, and spiny dogfish. In these four cases, the estimated bycatch landings exceeded the total recorded landings without addition of the directed fishery landings. In the first three cases, the fish were represented by a large number of tows with multiply-designated targets making the assignment of landings to bycatch or target categories ambiguous. In the last case, high landed bycatch species-to-landed target species ratios in the observed tows for certain target species were responsible (e.g., for landings of spiny dogfish in the silver hake fishery). In any case, very likely, the origin of these errors is biased estimates of bycatch landings from the observer reports. As a consequence, the estimates of discarding of species caught during targeted tows of the four target species could not be made and total estimates of discards for species with high discard-to-target landings ratios in these fisheries must be treated with caution.

Nevertheless, the analysis does reveal a level of adequacy of the observer database by permitting some degree of verification of the bycatch landings-to-target species landings ratios. The same level of adequacy must be accepted for the discards-to-target species landings ratios used for estimating total discards. This latter ratio cannot be independently verified as facilely.

Statistical Analysis

ANOVA analysis

ANOVAs testing the influence of target-species assignments or time of the tow during the trip included year as a main effect and all year*main effect interaction terms. We examined the time of the tow during the trip by dividing the trip into thirds based on the number of tows and assigned individual tows a value of 1, 2, or 3. Tows from single-tow trips were assigned a 3 because the analysis addressed issues of discarding produced by trip limits that come into play during the last part of the trip. Tows from dual-tow trips were assigned a 1 or a 3.

ANCOVAs were run using ranked raw variables (equivalent to a Kruskal-Wallis

test) that defined the environment (season, time-of-day, location, and depth), and variables describing fishing behavior (codend mesh size, effort, and total catch per tow). Year was included as a main effect in all models. Interaction terms between selected environmental variables were routinely included: season*depth, season*location, and depth*location. Total catch per tow and effort were used as covariates. Variables that defined possible biases in the data set (e.g., observer, boat) were not included because the degree of replication of observer-boat pairs throughout the geographic and temporal range of observed tows was low. In addition, fishermen may change their behavior with observers onboard (Liggins et al., 1997). We were unable to evaluate the potential influence of this effect.

Effort could not be calculated directly because the swept area of the tow was not recorded, nor could swept area be calculated from the recorded data. A surrogate for true effort was obtained as the average of the recorded headrope and footrope lengths multiplied by the recorded tow time and speed. The multiple of tow time and speed is superior to the distance between tow initiation and cessation because tow paths may not be linear (Powell et al., in press, submitted b).

Class variables used in the ANCOVAs were developed by combining tow days, times-of-day, depths, and locations into larger categories (bins). The binning plans used for season, time-of-day, and depth are shown in Tables 1-3. Months were combined into four seasons wherever possible. Reduced data richness necessitated coarser groupings in some cases. Time-of-day for each tow was calculated by taking the mean of the times of net deployment and retrieval. Time-of-day segments were allocated to four time segments dividing daylight and nighttime into 6-hour time intervals wherever possible. Reduced data richness necessitated coarser categories in some cases, minimally 12-hour time segments separating day and night. Depth for each tow was calculated as the mean of the depth at net deployment and the depth at net retrieval. Depth intervals were lumped into 20 m categories wherever possible. Coarser categories were normally required over some portion of the depth range. Locations were defined as major geographic areas: Cape Hatteras to Chesapeake Bay, Chesapeake Bay to Delaware Bay, Delaware Bay to Hudson Canyon, Hudson Canyon to Block Island, Block Island to Cape Cod, the western half and eastern half of Georges Bank, and the Gulf of Maine. Not all target species were represented by observed tows in all of these areas.

Spatial Autocorrelation

The spatial-temporal distribution of scup-discarding events was examined using spatial autocorrelation (Cliff and Ord, 1973), as described by Sokal and Oden (1978) and Powell et al. (1987). Geary's C was used as the test statistic:

$$C = \left(\frac{n-1}{2W}\right) \frac{\sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{ij}(x_i - x_j)^2}{\sum_{i=1}^{n} z_i^2} \quad (4);$$

where

$$W = \sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{ij}, \quad (5)$$

$$z_i = x_i - \bar{x}, \quad (6)$$

n = number of samples, x_i = datum of each sample i, and w_{ij} = a weighting measure as described subsequently. Significance levels were calculated as described by Jumars et al. (1977) under the assumption of randomization.

Geary's C was chosen because it is sensitive to sample-to-sample variation $(x_i - x_j)$. Fish stocks continuously reorient themselves in space in a temporally dynamic fashion. As a consequence, some portion of the stock is continuously interacting with other portions of the stock and, thusly, sample-to-sample variation is an important descriptor of spatial arrangement. Values of Geary's C above 1.0 indicate negative spatial autocorrelation, an even distribution. Values below 1.0 indicated positive spatial autocorrelation, a patchy distribution.

The calculation of Geary's C is contingent on the choice of a weighting system (w_{ij}) which is a mathematical representation of the spatial relationship of the samples. We used a "Queen's moves" approach in which tows a designated distance or time apart were assigned $W_{ij} = 1.0$ and all others were assigned $W_{ij} = 0$.

The change in spatial relationship with distance or time was examined using correlograms (plots of similarity versus distance or time between samples). Sample-to-sample distances were calculated as straight-line distances in multiples of 18.533 km (=10 minutes of latitude). Tow pairs that fell within a designated distance category were assigned $W_{ij} = 1.0$ for that analysis. Sample-to-sample elapsed times were calculated in Year-days with the start of each year assigned as Year-day 1. Elapsed-time categories were established in multiples of 30 days. Tow pairs that fell within a designated elapsed-time category were assigned $W_{ij} = 1.0$ for that analysis.

Results

Target Species

Thirty-five target species were discriminated in the database. Of these, four were unknown species types. The remaining 31 were unambiguous designations or could be identified from ambiguous declarations (Table 4). These target species provided a range of data richness. Some target species were represented by numerous trips and tows. *Loligo* squid, for example was represented by 178 trips and 1,597 tows (Table 4). At the other extreme were fish such as bluefish with two trips and four tows. These latter species were deleted from most analyses. Intermediate, and of more consequence, were species such as scup or black sea bass with >5-to-<30 trips and/or >10-to-<100 tows. The representativeness of these smaller datasets within the larger database cannot be fully evaluated. In the one independent test, however, Bochenek et al. (submitted) found few significant differences between the NMFS observer reports for scup and black sea bass and an independently obtained dataset using the same methodology. The inference is that the observer reports for the intermediate group of target species are reasonably representative, even thought the dataset is sparse. The data of Bochenek et al. (submitted) were included in analysis of these two target species.

Some target species were routinely declared or inferred to be present in multiply-targeted tows (Table 5). In most tows, for example, where pollock was a target species, three or four other target species were also declared. In contrast, most *Loligo* squid-targeted tows were tows where that species was the only declared target. Highest multiple-target occurrence rates included cod, haddock, pollock, redfish, American plaice, witch flounder, winter skate, and American lobster. Species with fewest multiple targets included *Loligo* and *Illex* squid, butterfish, silver hake, scup, black sea bass, summer flounder, yellowtail flounder, Atlantic mackerel and Atlantic herring, little skate, and sea scallops.

Distribution of Landings – 2001

The estimation of yearly discards requires estimating the fraction of total target species landings that occurred in the directed fishery [equation (2)]. In most cases, the total number of observer reports for a given target species was too few to conduct this evaluation on a single year's data. We, therefore, combined years 1997-2001. The obvious assumption is that the ratio of bycatch landings-to-landings in the

directed fishery is constant during this period. In a few cases, changes in fishery regulations make this unlikely [e.g., spiny dogfish (MAFMC, 2002)]. Estimates of the division of landings between bycatch and directed-fishery landings carry this caveat.

The small-mesh fisheries, as typically regulated, include Atlantic mackerel, *Loligo* squid, silver hake, and black sea bass. In addition, the butterfish fishery typically uses a small-mesh codend. The estimated distribution of landings for species landed in the small-mesh fisheries is shown in Table 6. The division of landings into bycatch and directed fishery landings for each target species is listed in Table 7. Landings in the directed fishery accounted for most of the landings in all small-mesh fisheries except black sea bass. A substantial volume of black sea bass was landed from scup, butterfish, silver hake, summer flounder, and *Loligo* squid-targeted tows (Table 6). Essentially all Atlantic mackerel were landed from mackerel-targeted tows. Butterfish-targeted tows produced a considerable volume of landed silver hake and *Loligo* squid. Silver hake and *Loligo* squid-targeted tows each produced a considerable landings volume of the other species. Thus, small-mesh fisheries produced most of the landings of other small-mesh-targeted species. Butterfish, not typically a focus of small-mesh fishery regulations, also produced a considerable landings volume of other small-mesh species (Table 6) and has been included in all further analyses.

Distribution of Discards in the Small-Mesh Fisheries – 2001

The distribution of discards in the five small-mesh fisheries for species targeted by other commercial fisheries is shown in Table 7. The dominant recreationally and commercially-important species discarded by *Loligo* squid fishermen included silver hake, butterfish, spiny dogfish, *Loligo* squid, summer flounder, Atlantic mackerel, and *Illex* squid (Table 7). Each of these produced in excess of 200,000 kg of discards in 2001.

In the directed fishery for silver hake, significant discards of commercially-important species included silver hake, butterfish, spiny dogfish, *Loligo* squid, and monkfish. Each of these exceeded 300,000 kg of discards in 2001 (Table 7). Significant discards in the butterfish-directed fishery included butterfish, *Loligo* squid, silver hake, scup, summer flounder, weakfish, and spiny dogfish. Discarding was inconsequential in the Atlantic mackerel-directed fishery. The black sea bass fishery was an important source of discards only for scup. Scup discarding has been

considered in a companion analysis (Powell et al., submitted a). As a consequence, we focus hereafter on discarding in the *Loligo* squid, silver hake, and butterfish-directed fisheries. The nine discarded species of most importance in these three fisheries were *Loligo* squid, silver hake, Atlantic mackerel, butterfish, *Illex* squid, summer flounder, spiny dogfish, weakfish, and monkfish. These nine were chosen for their numerical dominance in the list of discards provided in Table 7 or due to their fractional importance in comparison to landings (Table 7).

Distribution of Discards of Selected Species – 2001

Highest *Loligo* squid discards occurred in the *Loligo* squid, silver hake and butterfish fisheries (Table 8). The total fishery-wide discard rate for *Loligo* squid was about 7.3% of landings (Tables 7, 8), so, although the discard rates for *Loligo* squid in the *Loligo* squid, silver hake, and butterfish fisheries appear high, they are, in fact, inconsequential in comparison to landings as a source of yearly mortality.

A substantial volume of *Illex* squid was discarded in *Loligo*-targeted tows (Table 8). Total *Illex* discards were about 60% of *Illex* landings in 2001. About 64% of these discards occurred in *Loligo*-targeted tows. Year 2001 was a particularly poor year for *Illex* landings (Powell et al., submitted b), which may have exacerbated the landings-to-discards ratio for *Illex* in comparison to other years.

Silver hake were discarded in highest volumes in the directed fishery and the *Loligo* squid fishery. Total yearly discards were 37% of landings (Tables 7, 8). Of these, 78% occurred in the directed fishery and the *Loligo* squid fishery.

Discards were a very small fraction of landings for Atlantic mackerel (4.4%). In contrast, discards of butterfish equaled about 132% of butterfish landings (Tables 7, 8). Highest discard sources included the *Loligo* squid, butterfish and silver hake fisheries (Table 8) that collectively accounted for 94.3% of all butterfish discards.

Summer flounder discards were significant in a relatively wide range of directed fisheries. In aggregate, total discards of summer flounder equaled about 40.6% of summer flounder landings. This is likely a minimal estimate due to the restricted range of sea scallop dredge hauls analyzed (Table 8). Fisheries yielding the highest volumes of summer flounder discards included the *Loligo* squid, silver hake, butterfish, sea scallop, and summer flounder fisheries. The three small-mesh fisheries accounted for up to 58.6% of total yearly summer flounder discards, equivalent to about 23.8% of summer flounder landings, remembering again the

caveat that some sea-scallop dredge hauls were not analyzed.

Spiny dogfish discards far exceeded landings (Tables 7, 8). Discards were high in a wide range of fisheries. Butterfish, silver hake, and *Loligo* squid accounted for three of the top five fisheries discarding spiny dogfish. The other two were cod and monkfish. Not far behind were the winter flounder, summer flounder, and yellowtail flounder fisheries. Discards of spiny dogfish in each of the top five discarding fisheries exceeded by a substantial margin landings of spiny dogfish reported in 2001 (Tables 7, 8).

Discards of weakfish amounted to about 71.8% of reported landings in 2001. Butterfish and Atlantic croaker-targeted tows accounted for most of these. Discards of monkfish in the small-mesh fisheries were seemingly high (Table 8) until compared with discards in the directed fishery. More than half of all discarded monkfish were discarded in the directed fishery. Total discards of monkfish, all directed fisheries combined, equaled only about 20.6% of monkfish landings.

The analysis identifies thirteen target species-discard species pairs in which discarding in the small-mesh fishery was likely an important source of total yearly mortality for the discarded species. These are: *Loligo* squid-*Illex* squid, silver hake-silver hake, *Loligo* squid-silver hake, *Loligo* squid-butterfish, butterfish-butterfish, silver hake-butterfish, *Loligo* squid-spiny dogfish, silver hake-spiny dogfish, butterfish-spiny dogfish, butterfish-weakfish, *Loligo* squid-summer flounder, silver hake-summer flounder, and butterfish-summer flounder. Additionally, we have considered the three most important sources of *Loligo* squid discards: *Loligo* squid-*Loligo* squid, silver hake-*Loligo* squid, and butterfish-*Loligo* squid.

Frequency of High-Discard Events

Although high discards in a fishery may occur due to many tows each with a few discards, high-discarding events often contribute disproportionately to total discards. High-discarding events of *Illex* squid, defined as >100 kg tow^{-1}, occurred predominately in *Loligo* squid and *Illex* squid-targeted tows. High-discarding events accounted for 2% and 6% of total targeted tows (Table 9). High-discarding events of silver hake occurred primarily in *Loligo* squid and silver hake-targeted tows. The rate of occurrence of high-discarding events was 14% and 15%, respectively (Table 9).

Among the small-mesh fisheries, *Loligo* squid, butterfish, Atlantic mackerel,

and silver hake-targeted tows produced the highest incidence of high butterfish-discarding events. The frequency of high-discarding events exceeded 9% for each of these and rose as high as 28% for butterfish-targeted tows. High-discarding events of spiny dogfish were common in *Loligo* squid, silver hake, Atlantic mackerel, and butterfish-targeted tows. The frequency of such events exceeded 5%. Extreme discarding events (>1,000 kg tow^{-1}) were also recorded.

Butterfish accounted for a few high-discarding events of weakfish (Table 9). The *Loligo* squid and silver hake fisheries produced most of the high-discarding events for summer flounder (Table 9). High-discarding events of *Loligo* squid were relatively rare, the frequency rising above 3% only for the *Loligo* squid, butterfish, and silver hake fisheries (Table 9). Accordingly, nearly all of the sixteen previously-identified target species-discard species pairs were characterized by a disproportionate number of high-discarding events.

Origin of Discards and Bias

Market considerations controlled *Illex* squid discarding in the *Loligo* squid, silver hake, and butterfish fisheries (Table 10). The same was true for butterfish, *Loligo* squid, silver hake, and weakfish discarding in these three small-mesh fisheries. Spiny dogfish were discarded primarily for the same reasons; however, in the *Loligo* squid fishery, regulatory limitations accounted for about 34% of the spiny dogfish discards. Thirty to 40% of summer flounder discards in the *Loligo* squid and silver hake-directed trips originated from market considerations; however, quota restrictions accounted for about one-third of the discards of summer flounder in *Loligo* squid and butterfish-targeted tows (Table 10).

Given that trip limits are imposed for many commercial species, discarding of some regulated species might be expected to increase towards the end of the trip. We compared the first, middle, and last third of the trip. Discarding did not occur at a significantly different rate during any trip segment (ranked ANOVA, $P > 0.05$) for any target species-discard species pair with the exception of *Illex* squid discarded in silver hake-targeted tows (ranked ANOVA, $P = 0.017$), nor did any trip segment contribute significantly more to bycatch species landings (ranked ANOVA, $P > 0.05$). Given the number of tests, 21, the incidence of significant differences, 1, is no more than would be expected by chance (Binomial test, $\alpha = 0.017$).

Most targets were unambiguously declared by the Captains. However, in some cases, ambiguity existed in the declarations. We compared the discard rates in tows

where the target species was determined *a posteriori* with those tows for which the target species was unambiguously declared at sea. Four significant differences were observed out of 21 possible, a rate substantially beyond that expected by chance (Binomial test, $P < 0.0001$ at $\alpha = 0.03$). These cases were discarding of spiny dogfish in butterfish-targeted tows (ranked ANOVA, $P = 0.025$), discarding of silver hake in *Loligo* squid-targeted tows (ranked ANOVA, $P = 0.0079$), discarding of spiny dogfish in silver hake-targeted tows (ranked ANOVA, $P = 0.03$), and discarding of silver hake in silver hake-targeted tows (ranked ANOVA, $P < 0.0001$). In all four cases, the discarding rate for the tows with ambiguous target designations was lower. This is doubtless due to the fact that most ambiguous target designations resulted in multiply-declared targets, and the discards were distributed evenly amongst these for analysis. In the latter three cases, the total number of ambiguous tows was small, so that the overall impact on discarding was low. In the first case, discarding of spiny dogfish in butterfish-targeted tows, about 40% of tows were ambiguous. In summary, although ambiguous target declarations had the potential to significantly impact the discard analysis, due primarily to their relatively low number, their impact was small. However, the already high discard estimate for spiny dogfish in butterfish-targeted tows (Table 8) may be an underestimate.

The declaration of multiple targets significantly influenced the estimated discard rate of some species. For butterfish-targeted tows, discards of butterfish (ranked ANOVA, $P < 0.0001$) and summer flounder (ranked ANOVA, $P = 0.006$) tended to be higher in tows with three declared targets than in tows with a single target declared. *Loligo* squid discards were significantly higher in tows with single or dual declared targets than in tows with three targets declared (ranked ANOVA, $P = 0.0018$, Tukey's Studentized Range Test, $\alpha = 0.05$). Had the discards for multiply-targeted tows been applied in full to each target species, in addition to these two species, silver hake discards would have been significantly higher in triply-targeted tows in comparison to tows with a single target declared (ranked ANOVA, $P = 0.03$). In addition, *Loligo* squid discards in dually-targeted tows would have been significantly higher than in tows with a single target declared (Tukey's Studentized Range test, $\alpha = 0.05$). For *Loligo* squid-targeted tows, if all discards were distributed to each target in multiply-targeted tows, tows with three or more targets consistently had more discards of butterfish (ranked ANOVA, $P < 0.0001$) and summer flounder (ranked ANOVA, $P = 0.0009$) than singly-targeted tows. Distributing discards evenly among declared targets eliminated

much of this tendency, in contrast to butterfish-targeted tows. However, *Loligo* squid discards were now significantly lower in tows with three targets declared than in other tows (ranked ANOVA, $P = 0.018$). For silver hake-targeted tows, when all discards were allocated to each declared target, butterfish discards were higher in tows with three declared targets than in singly-targeted tows (ranked ANOVA, $P < 0.0001$). The reverse was true for silver hake discards (ranked ANOVA, $P < 0.0001$). The same trends remained after apportioning discards among target species. In addition, *Illex* squid discards averaged higher in singly-targeted tows (ranked ANOVA, $P = 0.008$). Overall, the analysis suggests a strong tendency for discarding to be higher in tows with multiply-declared targets.

In the previous set of analyses, interaction terms with year were significant ($\alpha = 0.05$) in 12 of 21 tests. This rate of occurrence is much above that anticipated by chance (Binomial test, $P < 0.0001, \alpha = 0.05$). One source of these interactions might be the change in database structure for target species declarations after 2000 that could facilitate an increase in multiple target designations and introduce a bias due to the propensity for multiply-targeted tows to be characterized by increased discarding. The number of multiply-targeted tows in which one of the seven species was discarded did not increase significantly after 2000 in butterfish-targeted tows. However, significantly more multiply-targeted tows in which butterfish (ANOVA, $P < 0.0001$), summer flounder (ANOVA, $P < 0.0001$), weakfish (ANOVA, $P = 0.0005$), *Loligo* squid (ANOVA, $P < 0.0001$), and *Illex* squid (ANOVA, $P = 0.014$) were discarded occurred after 2000 in the *Loligo* squid fishery. In the case of the silver hake fishery, the same trend of increased numbers of multiply-targeted tows after 2000 in which a species was discarded occurred for discards of butterfish (ANOVA, $P < 0.0001$), summer flounder (ANOVA, $P = 0.0012$), weakfish (ANOVA, $P < 0.0001$), spiny dogfish (ANOVA, $P < 0.0001$), *Loligo* squid (ANOVA, $P < 0.0001$), and silver hake (ANOVA, $P = 0.0011$).

Higher reported discards in multiply-targeted tows might insert an apparent increase in discarding after 2000. In the *Loligo* squid fishery, discarding was significantly increased for butterfish (ranked ANOVA, $P < 0.0001$), summer flounder (ranked ANOVA, $P < 0.0001$), and spiny dogfish (ranked ANOVA, $P < 0.0001$) after 2000. In the silver hake fishery, discarding was significantly increased after 2000 for butterfish (ranked ANOVA, $P < 0.0001$), summer flounder (ranked ANOVA, $P < 0.0001$), *Loligo* squid ($P = 0.04$), and spiny dogfish (ranked ANOVA, $P < 0.0001$). Two exceptions occurred to this trend in which discarding

was higher prior to 2001. These were silver hake discarding in silver hake-targeted tows (ranked ANOVA, $P < 0.0001$) and weakfish discarding in butterfish-targeted tows (ranked ANOVA, $P = 0.04$). Distributing the discards proportionately across each of the declared targets in multiply-targeted tows failed to change the significance of any of these trends substantially, although the mean quantity of discards per tow necessarily was modified. So, the tendency for an increased frequency of multiply-targeted tows after 2000 did not substantially bias year-to-year trends in discarding rate.

The previous analyses suggest that year of observation exerts a significant influence on the pattern of discarding in many cases, however. Not surprisingly, discarding in the butterfish fishery was not significantly influenced by year of observation. However, as expected, in the *Loligo* squid fishery, discards of butterfish (ranked ANOVA, $P < 0.0001$) were significantly influenced by year, as were discards of summer flounder (ranked ANOVA, $P < 0.0001$), spiny dogfish (ranked ANOVA, $P < 0.0001$), *Loligo* squid (ranked ANOVA, $P < 0.0001$), and *Illex* squid (ranked ANOVA, $P = 0.02$). For the cases of summer flounder, spiny dogfish, and *Illex* squid, discarding was higher after 2000 (Tukey's Studentized Range test, $\alpha = 0.05$). An *a posteriori* test indicated that discarding in summer flounder was significantly higher in 2001 and 2002 than in 1997 and that discarding of spiny dogfish was significantly higher in 2001 than in 1997 and 1998. The *a posteriori* test did not resolve the influence of year on butterfish discarding. For *Loligo* squid discarding in the *Loligo* squid fishery, although year of observation was significant, no directional tendency existed in the order of the years. In the silver hake fishery, discards of summer flounder (ranked ANOVA, $P < 0.0001$) were significantly influenced by year, as were discards of weakfish (ranked ANOVA, $P = 0.043$), silver hake (ranked ANOVA, $P = 0.0029$), and *Illex* squid (ranked ANOVA, $P = 0.043$). For silver hake, discarding in 2000 and 2001 was significantly higher than in 1997-1999 (Tukey's Studentized Range test, $\alpha = 0.05$). In the remaining cases, no directional tendency existed in the order of the years.

Influence of Season, Time-of-Day, Location and Depth

Season

Loligo squid-targeted trips were observed in each month. The number of tows was higher in the spring than in the fall, lowest in August and highest in March. Besides August, fewest tows were observed in May, September, and December

(Table 1). Tows in the silver hake-directed fishery were observed primarily in January and February, with a significant minority in March, April, July, October, and November (Table 1). Nearly all observed tows with butterfish as the target species occurred during January and February (Table 1), although a few tows were observed in the last three months of the year.

Season exerted a significant main effect in 9 of the sixteen key target species-discard species pairs (Table 11). Interaction terms with depth and location were significant in 15 of 22 possible cases (Table 11), a frequency much above that expected by chance (Binomial test, $\alpha = 0.05$, $P < 0.0001$). Most of these (12) were associated with *Loligo* squid-targeted tows.

Season of observation was significant in the *Loligo* squid fishery for discards of butterfish, *Loligo* squid, *Illex* squid, and spiny dogfish (Table 11). In each case, the period January-March was among the highest discarding seasons (Table 12). Discarding during the period October-December was high in two of three cases (butterfish, spiny dogfish) (Figure 1, Table 12). Discards-to-*Loligo* squid landings ratios were consistently above 0.2 for butterfish and exceeded 0.5 for some seasons for butterfish, spiny dogfish, and summer flounder. Season of observation was significant in the silver hake fishery for discards of *Loligo* squid, silver hake, spiny dogfish, and summer flounder (Table 11). In three cases, *Loligo* squid, summer flounder, and spiny dogfish, discards tended to be higher in the first half of the year (Figure 2, Table 12). For silver hake, discarding tended to be higher in July-September (Figure 2). For spiny dogfish, discards were also high in October-December. Discards-to-silver hake landings ratios were above 0.5 for at least one season for butterfish, *Illex* squid, silver hake, spiny dogfish, and summer flounder. The discards-to-silver hake landings ratio exceeded 1.0 for butterfish and spiny dogfish in tows taken between January and March. Season of observation was significant in the butterfish fishery for weakfish. Discards were highest in October-December (Figure 3). Discards-to-butterfish landings ratios exceeded 1.0 for most other discarded species during the period January-March (Table 12).

Time-of-Day

Loligo-targeted tows were primarily conducted during daylight hours as a consequence of the diel vertical migration characteristic of this species (Serchuk and Rathjen, 1974), although a not insubstantial number of tows nevertheless occurred at night (Table 2). Butterfish-targeted tows occurred primarily during daylight

hours and into the early evening (Table 2). Silver hake-targeted tows were also biased towards daylight tows with more nighttime tows occurring during the evening than early in the morning (Table 2).

In contrast to season, time-of-day rarely exerted a significant effect on discarding. Significant effects were limited to *Illex* squid and silver hake discards in the *Loligo* squid fishery and *Loligo* squid in the silver hake fishery (Table 11). Each of these involves a species with a tendency towards diel-induced behavior (Serchuk and Rathjen, 1974; NEFSC, 2002c; Gillis, 1999). Silver hake discards were highest during nighttime in *Loligo* squid-targeted tows. The silver hake discards-to-*Loligo* squid landings ratio exceeded 0.8 during this time period (Table 13). *Loligo* squid discards were highest during the day in silver hake-targeted tows, as might be expected from the diel migratory behavior of this squid, although the average discards-to-landings ratio did not vary much between day and night (Table 13).

Depth

Loligo-targeted tows occurred at depths of 1 to 350 m, but most tows fell between 1 and 40 m and between 60 and 180 m (Table 3). Most observed silver hake-targeted tows were taken between 40 and 100 m (Table 3). Observed butterfish tows were taken predominately between 80 and 140 m (Table 3). Interaction terms with depth were significant in 18 of 27 cases a frequency above that expected by chance (Binomial test, $\alpha = 0.05$, $P < 0.0001$).

Depth exerted a significant effect on discarding in seven of sixteen cases, a frequency above that expected by chance (Binomial test, $\alpha = 0.021$, $P < 0.0001$) (Table 11). Most weakfish discarded in butterfish-targeted tows were caught between 0 and 60 m depths (Table 14). Discards of butterfish and silver hake in *Loligo* squid-targeted tows reached greatest volume in depths of 60 to 120 m. The discards-to-*Loligo* squid landings ratio exceeded 0.5 for both discarded species at these depths (Table 14). In both cases, the next deepest depth stratum (120-180 m) produced more discards than the shallower stratum (0-60 m). *Illex* squid were discarded in greatest volume from tows taken in depths below 120 m. Butterfish, summer flounder and *Loligo* squid discarding was highest in silver hake-targeted tows that took place at depths of 60 to 180 m. Discarding volume for all three species tended to be higher in tows taken in 60 to 120 m than in 120 to 180 m, although, in two of the three cases, the discards-to-silver hake landings ratios were considerably higher in tows taken between 120 and 180 m (Table 14).

Location

Observed butterfish tows occurred primarily from Cape May to south of Nantucket. The majority were sited on the outer continental shelf, although some inshore tows were observed off the Delmarva Peninsula and off Long Island. *Loligo*-targeted tows were observed throughout the Mid-Atlantic region from near Cape Hatteras to Georges Bank. Although most observed tows were taken along the outer continental shelf, a substantial minority were nearshore and, off Long Island and Massachusetts, on the central continental shelf. Silver-hake targeted tows were observed over a wide geographic range from off New Jersey into the Gulf of Maine. Although most observed tows were taken along the outer continental shelf, inshore tows were observed in the upper reaches of Hudson Canyon and south of Rhode Island and Massachusetts (Figures 1-3).

Geographic location exerted a significant influence on discarding in butterfish, *Loligo* squid, and silver hake-targeted tows in 12 of sixteen cases, a frequency much above that expected by chance (Binomial test, $\alpha = 0.046$, $P < 0.0001$). Interaction terms between season or depth and location were significant in 19 of 27 cases, a frequency also much above that expected by chance (Binomial test, $\alpha = 0.05$, $P < 0.0001$) (Table 11).

Discarding of spiny dogfish, *Loligo* squid and weakfish in butterfish-targeted tows did not occur equitably among all geographic regions. Discarding occurred over a rather narrow depth and seasonal range due to the depth- and season-restricted distribution of observed butterfish-targeted tows. Spiny dogfish were discarded in greater volume in butterfish-targeted tows taken between Hudson Canyon and Cape Cod where the discard-to-landings ratio exceeded 5.0 (Table 15). Discarding declined significantly south of Hudson Canyon (Tukey's Studentized Range test, $\alpha = 0.05$) (Figure 3). Weakfish discarding events were areally restricted inshore. Tows taken between Hudson Canyon and Block Island produced most discards (Figure 3). Significantly more *Loligo* squid were discarded between Delaware Bay and Hudson Canyon than elsewhere. The discards-to-landings ratio exceeded 7.0 in this region (Table 15). Significantly fewer *Loligo* squid were discarded between Hudson Canyon and Block Island (Figure 3).

Discarding of butterfish, *Illex* squid, *Loligo* squid, silver hake, and summer flounder did not occur equitably among all geographic regions in *Loligo*-targeted tows. Discarding of butterfish was significantly higher in tows located between Cape

Hatteras and Chesapeake Bay (Figure 1). Discarding was not significantly different across the vast majority of other regions (Table 15). Discards of *Illex* squid were also significantly higher in tows taken between Cape Hatteras and Chesapeake Bay than elsewhere (Figure 1). Discards tended to be higher in tows taken from Block Island through Georges Bank than between Chesapeake Bay and Block Island, although not all subregions within these two broader geographic regions differed significantly from the others. Silver hake discards were significantly higher on Georges Bank than elsewhere (Figure 1). The discards-to-landings ratio exceeded 1.0 in tows taken on the eastern half of Georges Bank (Table 15). Discards were significantly lower in tows taken from Cape Hatteras to Delaware Bay (Figure 1). Summer flounder discards were highest in tows taken from Block Island through the western half of Georges Bank (Figure 1). Discards tended to be significantly lower in tows taken on the eastern half of Georges Bank and from Cape Hatteras to Hudson Canyon (Figure 1). Discards of *Loligo* squid tended to be higher in tows taken from Hudson canyon east, in comparison to tows taken south of Hudson Canyon (Figure 1). Highest discards occurred on the western half of Georges Bank. Lowest discards occurred in tows taken from Cape Hatteras to Hudson Canyon.

Interaction terms between location and depth or season were always significant for each discarded species in *Loligo* squid-targeted tows, indicating substantial fine-scale spatial and temporal variability in discarding. For example, high-discarding events of summer flounder tended to occur later in the year on Georges Bank than in regions farther to the west (Figure 1). Butterfish discarding tended to be high later in the year south of Hudson Canyon than east of it (Figure 1). Spiny dogfish discards tended to predominate in tows taken inshore of the shelf edge during late fall south of Hudson Canyon, but offshore, near the shelf edge, during winter and early spring (Figure 1).

Discarding of butterfish, *Loligo* squid, silver hake, and summer flounder did not occur equitably among all geographic regions in silver hake-targeted tows. An *a posteriori* test did not differentiate regions with respect to the degree of butterfish discarding, although the discards-to-silver hake landings ratio was highest in tows taken between Hudson Canyon and Block Island (Table 15). Discarding of *Loligo* squid in silver hake-targeted tows was significantly higher from Hudson Canyon to Block Island than elsewhere (Figure 2). Discards were significantly lower than elsewhere south of Hudson Canyon and on Georges Bank (Figure 2). Silver hake discards were highest in tows taken from Block Island through Georges Bank and

lowest west and south of Block Island (Figure 2). Intermediate values came from the Gulf of Maine. Summer flounder discards were highest in tows taken from Hudson Canyon to Block Island where the discard-to-landings ratio exceeded 0.5, somewhat lower from Block Island to Cape Cod, and significantly lower elsewhere (Figure 2, Table 15).

Although less frequent than in *Loligo*-targeted tows, interaction terms between location and depth or season tended to be significant for most species discarded in silver hake-targeted tows (Table 11). Depth tended to have a much more significant influence on discarding than season. That is, discards tended to vary much more with depth among locations than with season among locations.

Fishing Practice

We utilized the variables total catch per tow, effort per tow, and codend mesh size to describe the fishing characteristics of each tow. Effort generated a significant effect on discard rate in only four cases (Table 11); nevertheless this frequency was still greater than expected by chance (Binomial test, $\alpha = 0.05$, $P < 0.005$). In two cases, the rate of discarding increased with increasing effort. In two, the rate of discarding decreased with increasing effort. In only one case did the level of significance exceed $\alpha = 0.001$. In contrast, codend mesh size generated a significant relationship with discarding rate in 10 of 21 cases and total catch did so in 12 of 21 cases. Both frequencies are greater than expected by chance (Binomial test, $\alpha = 0.03$, $P < 0.0001$). In many of these cases, the level of significance exceeded $\alpha = 0.001$ (Table 11). Not surprisingly, discarding normally increased significantly with increasing catch (11 of 12 cases that were significant). Curiously, discarding normally increased with increasing mesh size (9 of 10 cases that were significant).

Spatial Autocorrelation

ANCOVA analysis indicates that time-of-year significantly influenced discarding of most (9 of 14 possible cases) of the seven species under consideration in the silver hake and *Loligo* fisheries and that geographic region had an even greater influence (11 of 14 possible cases). The frequency of highly-significant interaction terms also suggests that the spatial-temporal distribution of discarding events is variable over small spatial and temporal scales. For the silver hake and *Loligo*-directed fisheries, enough observed tows were available throughout the year (Table 1) to investigate the spatial-temporal stability of discarding events in more detail.

We evaluated the spatial-temporal pattern in discarding using the Geary's C test statistic. Because the number of observed tows in any one year did not provide adequate spatial-temporal coverage, perforce we assumed that the spatial-temporal pattern was relatively invariant between years. This assumption places a stern limitation on the analysis, but would, of course, be the underlying assumption for any area-time management plan to reduce discarding. We examined spatial-temporal stability using two-dimensional correlograms with time and distance on the axes, looking specifically for trends in the Geary's C statistic from low (positive autocorrelation) to high (negative autocorrelation) values from the shortest time-distance scale of 18 km and 30 days (lower left corner, Figure 4) to ever increasing distances and times. Such trends are routinely used to address the dimension of patchiness in populations (Sokal and Oden, 1978; Powell et al., 1992; Kim and Powell, 1998)

Target species-discard species pairs fell into two categories. In nearly all cases, the pattern of discarding tended to be stable over periods of 15 to 30 days and distances of 18 to 37 km, but no longer or farther. This limited degree of spatial-temporal stability in discarding described *Illex* squid, *Loligo* squid, butterfish, weakfish, and summer flounder discarding in the silver hake fishery and summer flounder, *Loligo* squid, weakfish, spiny dogfish, and *Illex* squid discarding in the *Loligo* squid fishery (examples in Figure 4). A contrasting pattern appeared for butterfish and silver hake discarding in *Loligo*-targeted tows and for silver hake and spiny dogfish in silver hake-targeted tows (Figure 4). Here, the spatial and temporal scales of discarding could not be resolved. The pattern of discarding was relatively similar in time and space over a wide range of temporal and spatial scales. Put another way, no preferred spatial scale existed.

Discussion

Perspective

The small-mesh fisheries of the Mid-Atlantic are considered potential sources of significant discarding because they employ a small-mesh codend, normally <6.5 cm, and because the total volume of landings is relatively high. Thus, small volumes of discards per tow might nevertheless, aggregate to a considerable total volume of yearly discards.

All tows result in some discards. Evaluating the importance of discarding

in the small-mesh fisheries requires first discriminating a discarding problem from the more inconsequential discarding that must accompany all fishing activities. A critical-point prescript would delineate discarding volumes of consequence from less weighty volumes based on their influence on stock sustainability, not that the latter should be treated with insouciance, but that the former should receive earnest attention. One obvious metric is the fraction of total fishing mortality contributed by discards. A different, but yet justifiable, metric is the proportion of total discards in a target-species fishery contributed by an individual species. Discarding may be more consequential if one species is discarded in higher volumes than another species, regardless of the inherent status of the discarded species' stock. A third, and also legitimate, metric is the fraction of total discards of a given species contributed by any one directed fishery. Discarding is more consequential if discarding of the species in a given directed fishery accounts for a substantial volume of all discards for the discarded species.

Conceivably discarding in a species might be viewed as consequential by any one of these metrics, but not the others. Identifying discards of greatest concern in the small-mesh fisheries, however, involves identification of those target species-discard species pairs qualifying for consideration by all three metrics. Once target species-discard species pairs of consequence are identified, the origins of discarding must be considered. These may be regulatory or market-driven, but also can be anticipated to be influenced by the distribution of target and discarded species in space and time. Such information is necessary before regulatory measures to reduce discarding can be formulated.

Identification of Consequential Discards

Scup is a significant discard by all three metrics, but has been dealt with elsewhere (Powell et al., submitted a). Scup will not be considered further here.

Metric 1: High Discarding Volume among Discarded Species

Consideration of the level of discarding of various species within each of the small-mesh target fisheries, *Loligo* squid, Atlantic mackerel, silver hake, black sea bass and butterfish, immediately identifies two fisheries where discarding is generally of little consequence, Atlantic mackerel and black sea bass (Table 7), disregarding the discarding of scup in black sea bass-targeted tows. In the other three fisheries, *Loligo* squid, silver hake, and butterfish, some important commercial and recreational species were characterized by high levels of discarding when

compared to other species caught and discarded in these fisheries. The analysis identifies sixteen target species-discard species pairs that might be considered of consequence by this metric. Seven occur in the *Loligo* squid fishery: *Loligo* squid, silver hake, butterfish, spiny dogfish, summer flounder, Atlantic mackerel, and *Illex* squid. Six occur in the silver hake fishery: *Loligo* squid, silver hake, butterfish, summer flounder, monkfish, and spiny dogfish. Six occur in the butterfish fishery: *Loligo* squid, butterfish, silver hake, summer flounder, weakfish, and spiny dogfish.

A number of these species are important discards in all three target fisheries: *Loligo* squid, silver hake, butterfish, summer flounder, and spiny dogfish. Three of these are the three target species, themselves, and these are all discarded in substantial quantities by the targeted fishery for the discarded species and each of the other two small-mesh fisheries. The other two species, summer flounder and spiny dogfish, rank high in discard volume in all three small-mesh fisheries.

Metric 2: High Discarding Volume-Landings Volume Ratio

The importance of discarding to total fishing mortality in these nine species can be estimated from data provided in Tables 7 and 8. Commercial discards contribute substantially to total commercial fishing mortality for butterfish, spiny dogfish, weakfish, summer flounder, *Illex* squid and silver hake (Table 16). In each case, more than 25% of total commercial catch is discarded. Discarding of *Loligo* squid, monkfish, and Atlantic mackerel are considerably less consequential.

Of the six species identified by this metric, in all cases, the small-mesh fisheries contribute considerably above 50% to total discards. Nearly all of the discards of these species in the small-mesh fisheries occur in the silver hake, butterfish, and *Loligo* squid fisheries. The metric identifies a subset of the sixteen previously identified target species-discard species pairs. Five occur in the *Loligo* squid fishery: silver hake, butterfish, spiny dogfish, summer flounder, and *Illex* squid. Four occur in the silver hake fishery: silver hake, butterfish, summer flounder, and spiny dogfish. Five occur in the butterfish fishery: butterfish, silver hake, summer flounder, weakfish, and spiny dogfish.

Metric 3: High Discarding Volume among Target Species

One can examine the distribution of discards of the six species identified by metric 2 in all targeted fisheries where sufficient information is available for analysis (Table 8). Silver hake discards are concentrated in the *Loligo* squid and silver hake fisheries. Discards in butterfish-targeted tows rank fourth after these two and monkfish and represent only about 10% of the discard level observed in silver hake-targeted tows. The vast majority of *Illex* squid discards occur in *Loligo* squid-targeted tows. Butterfish discards are concentrated in *Loligo* squid, silver hake, and butterfish-targeted tows. Butterfish and Atlantic croaker-targeted tows account for most weakfish discards.

Summer flounder discards are distributed among a number of target species. Largest discard volumes are produced by the silver hake fishery. Four fisheries vie for second place: sea scallop, summer flounder, butterfish, and *Loligo* squid. None of these reach much beyond half the level of discarding in the silver hake fishery and, of these, only butterfish accounts for more than 15% of total summer flounder discards. Spiny dogfish discarding is high in butterfish, silver hake, monkfish, cod, and *Loligo* squid-targeted tows. Only butterfish and silver hake contribute more than 10% to total spiny dogfish discarding.

The final metric identifies 10 target species-discard species pairs. Three occur in the *Loligo* fishery: silver hake, *Illex* squid, and butterfish. Four occur in the silver hake fishery: spiny dogfish, silver hake, butterfish, and summer flounder. Three occur in the butterfish fishery: weakfish, spiny dogfish, and butterfish.

Origin of Discards

Market considerations accounted for the vast majority of discards in the 10 target species-discard species pairs considered consequential by all three metrics. When a Captain declared a reason for the discard, small size was generally the reason declared. Discarded individuals were too small for the market. Quota restrictions can lead to few discards for four of these species, *Illex* squid, *Loligo* squid, butterfish, and silver hake. Butterfish is little regulated and *Illex* squid, *Loligo* squid, and silver hake are caught principally in targeted tows. None of the three have a legal size limit. Not surprisingly, then, few discards of these species are regulatory.

Spiny dogfish and summer flounder generate more surprise in that one might expect an increased fraction of regulatory discards. Both species are under

significant quota restrictions and size limits (MAFMC, 2002; NEFSC, 2000, 2002b). Murawski (1996) recognized the negative influence of size limits on discarding in the northeast U.S. commercial fisheries. As a consequence, the declared reasons for discarding of these species must be treated with a degree of skepticism. No reason was declared for a large fraction of the observed discards of summer flounder. For spiny dogfish, market considerations were given in most cases, despite regulatory restrictions. Regardless, the declared reason for discarding does not support the premise that regulatory discarding is an important component of discarding in the small-mesh fisheries. This characteristic distinguishes these species from scup where regulatory discards dominate the declared reasons for discarding (Powell et al., submitted a).

Options for Discard Reduction

Regulation not seemingly being of importance as a source of discarding diminishes the importance of simple regulatory reform in controlling discards of the six salient species discarded in the small-mesh fisheries. Furthermore, most target species-discard species pairs evince a low discard-to-target species landings ratio. For targeted *Loligo* squid tows, the discard-to-target species landings ratio for silver hake was 0.147, for *Illex* squid, 0.020, and for butterfish, 0.163. For targeted-silver hake tows, the discard-to-target species landings ratio for spiny dogfish was 0.212, for silver hake, 0.216, for butterfish, 0.100, and for summer flounder, 0.063. For targeted butterfish tows, the discard-to-target species landings ratio for weakfish was 0.052, for spiny dogfish, 0.557, and for butterfish, 0.701. With the exception of spiny dogfish and butterfish discarded in butterfish-targeted tows, all of these discard-to-target species landings ratios are relatively low; in five cases falling well below 0.2. Thus, landings volume would seem to be the primary driving force bringing to prominence these ten target species-discard species pairs, rather than high per tow catch and discard rates.

Confirmation accrues from the incidence of high-discarding events in these target species-discard species pairs. In most instances, the frequency of high-discarding events, >100 kg tow^{-1}, is low (see Ortiz, et al., 2000 for another example). With the exception of spiny dogfish and butterfish discarded in butterfish-targeted tows, the frequency of high-discarding events does not exceed 22%. In the latter two cases, the frequency exceeds 50%. A plot of these incidences of high-discarding events against the discard-to-target species landings ratios shows that high-discarding events oc-

curring more frequently than about 15% of the time are associated with rapidly increasing discard-to-landings ratios (Figure 5).

Low per-tow discarding rates minimize the effectiveness of most discard-reduction approaches, except gear technology, unless discarding is predictably distributed in time or space. We described the distribution of discarding in terms of season, time-of-day, depth, and location. Although more frequent than expected by chance in each case, substantive significant differences ($\alpha \leq 0.01$) occurred in only six of 28 cases for butterfish, 13 of 28 cases for *Loligo* squid, and 11 of 28 cases for silver hake. Time-of-day effects were rarely important. Thus, restricting fishing to certain times of day would normally not be effective in reducing discarding. Season, depth, and location were more frequent significant effectors of discard distribution. However, interaction terms routinely achieve significant levels higher than main effects and significant interactions tend to occur more frequently. This is particularly true in the *Loligo* squid fishery. Thus, the statistical analyses suggest a substantial amount of small-scale variability in the season, location, and depth of discarding.

A comparable evaluation of this issue is achieved through spatial autocorrelation. Two patterns exist. For most target species-discard species pairs, the scale of stability in time and space is small, typically no greater than 30 days and 18 km. Thus, for any given time and position, discarding differs significantly from coterminous space or time intervals. The pattern of discarding is not stable over long time periods or on large geographic scales. Compare to this the second pattern in which the spatial and temporal scales of stability of discarding are unresolved. *En masse*, the analyses suggest that space and time options for discard reduction are few and unlikely to be successful because tractable scales of stability in time and space do not exist.

On the other hand, in the majority of the ten consequential target species-discard species pairs, the declared reason for discarding is that the individual was too small to be marketed. This declared reason for discarding accounted for nearly all discarding of *Loligo* squid, silver hake, weakfish, and *Illex* squid. Thus, the obvious approach to managing discards of these species in the small-mesh fisheries is to more rigorously evaluate codend mesh sizes that might effect a reduction in the catch of undersized individuals (e.g., Halliday and Cooper, 2000).

In contrast, for spiny dogfish and summer flounder, small size is not a preponderant reason for discarding. Issues of quota tended to dominate the declared

reasons for summer flounder discards and unspecified market reasons were declared to account for most of the spiny dogfish discards. In aggregate, summer flounder discarding did not occur at an unusually high level. Regulatory discards due to quota restrictions are not easily minimized. In silver hake, where the greatest degree of concern might exist, depth tended to exert the largest single influence. A strong tendency existed for the largest discard events to be concentrated in tows taken on the outer continental shelf between Block Island and Nantucket. Most high-discarding events were observed in this area in January-April. This distribution explains the significance of season, depth, and location, and the interaction terms between depth and the variables season and location in summer flounder discarding in silver hake-targeted tows. However, discarding is not equivalently distributed in this area over time, as evidenced by the limited temporal stability uncovered by autocorrelation analysis. This instability is in keeping with the long-term and short-term instability of the Mid-Atlantic Bight hydrology (e.g., Glenn et al., 1996; Neuman, 1996; Parsons and Lear, 2001) and the seasonal migratory behavior evinced by many of the discarded and targeted species such as silver hake (Perry and Smith, 1994), *Loligo* squid (Serchuk and Rathjen, 1974; Brodziak and Hendrickson, 1998) and spiny dogfish (NEFSC, 1998). Thus, area-time approaches would require restrictions to be imposed over large areas for extended time periods. In the case of summer flounder discards in the silver hake fishery, a depth restriction might prove effective, however the use of gear limiting the capture of unwanted fish should also be investigated (e.g. Glass et al., 1999; Halliday and Cooper, 1999)

Spiny dogfish discards require closer inspection, particularly in butterfish-targeted tows. Spiny dogfish discarding events are frequent and discarding rate is high. Location was mildly significant in butterfish-targeted tows. Season was strongly significant in *Loligo* squid and silver hake-targeted tows. Most high discarding events in *Loligo* squid-targeted tows occurred from October to March. Most high-discarding events occurred from January to March in silver-hake targeted tows. Spiny dogfish discards were inordinately high in butterfish-targeted tows. High-discarding events were focused in a relatively small area southeast of Long Island and nearly all occurred in January. Since nearly all observed tows were in January, the practical significance of this observation is in doubt. A more detailed evaluation of spiny dogfish discards in the small-mesh fisheries, particularly butterfish, is clearly warranted, however. Consistent time-area management schemes will be difficult to implement however, as high-discarding

events tend to be widespread in time and space. Technological work on spiny dogfish excluder devices might be the most appropriate direction of research.

Bias in Target Declaration

Captains are asked to declare target species. This declaration is critical because regulations aimed at discard reduction must be specified for a directed fishery and only the Captain's declaration, perhaps augmented by recorded codend mesh size, provides the critical link between the observation of discarding and the regulated fishery. Moreover, as yearly discarding can only be estimated based on yearly recorded landings of target species, this declaration has additional importance. Two potential problems exist with target-species designations. In some cases, the declared target is ambiguous, e.g., 'unknown flounder'. In four cases, this ambiguity inserted a significant effect on the discard analysis. Two of these involve spiny dogfish and two involve silver hake. In all cases, the ambiguous tows had lower discards, indicating that discard-to-target species landings ratios would have been higher had these tows not been included.

The other source of potential bias is the increased ease of multiple target declarations subsequent to 2000 resulting from modification of the database structure. Multiply-targeted tows, on the average, were characterized by higher discarding. Why this should be true is unclear; however, the tendency was significant and consistent among most of the focal species in this report. One might suspect that fishermen less sure of their fishing acuity might declare alternatives more frequently. Such fishermen of lower astucity might also have increased catches of unwanted species and thus be characterized by higher levels of discarding.

Regardless of the reason, the fact that multiply-targeted tows had higher discarding rates and that multiple target declarations tended to increase after 2000 inserted a tendency for discarding to increase in a time-ordered fashion from 1997 through 2001. Accepting that the simple inclusion of additional multiple-target options resulted in higher at-sea discarding rates stretches credulity. Very likely, discarding has increased in actuality since 1997 in some cases and this increase has tended to bolster a behavioral tendency on the part of some Captains to increase the number of declared target species when discarding is likely to be high.

Of particular interest, discarding has increased in *Loligo* squid-targeted tows for a number of species despite efforts to reduce scup discarding through area-time closures (Powell et al., submitted a). This increase could not be fully explained by

the bias of multiple target declarations. Although confirmation that the change in boat distribution evoked by GRA creation is responsible for increased discarding is not possible, because no observed tows, perforce, are available from the GRAs, the institution of GRAs to control discarding in one species should be evaluated for the likelihood that differential effort distribution necessitated thereby has exacerbated discarding elsewhere for other bycatch species. The evidence certainly would support such an inference for the *Loligo* squid fishery.

Miscellaneous Biases

Regulations did not influence discarding, according to Captains declarations, in most cases. Not surprisingly, no tendency existed for discarding to increase towards the end of the trip for the small-mesh species as might otherwise be expected if trip limits substantially influenced discarding. Even for summer flounder, however, where quota issues were more important, trip limits appeared to have no substantial influence on the degree of discarding.

Observations were insufficient in number to include a number of target species in this analysis and the absence of landings data separated to species for skates prevented inclusion of these species. The limited number of observed tows in any one year also limited the evaluation of the influence of time-dependent variations in the bycatch landings-target species landings ratios to decompose total landings into target species landings and bycatch landings. These restrictions place some degree of limitation on the analyses conducted herein that cannot be evaluated beyond the caveat that is herewith included.

Conclusions

Present-day regulations focus on reducing discarding in the small-mesh fisheries. Determining what a significant discard is represents the first step in critically evaluating this emphasis. Analysis of the NMFS-NEFSC observer database for 1997-2001 augmented by some additional available information revealed a number of discard species-small-mesh target species pairs that met criteria imposed for discriminating significant discarding; namely, high discarding volume among discarded species, high discard-to-landings ratios for the target species, and high discarding volume among target species. This analysis identified ten target-species-discard species pairs of consequence as delineated by the three metrics: three in the *Loligo* fishery – silver hake, *Illex* squid, and butterfish; four in the silver hake fishery – spiny

dogfish, silver hake, butterfish, and summer flounder; and three in the butterfish fishery – weakfish, spiny dogfish, and butterfish.

The vast majority of these discards originate in the capture of undersized individuals. In nearly every such case, market considerations, not regulated size limits, drove the discard. More careful attention to codend mesh size restrictions might offer an opportunity to address this issue. In several cases, discarding was due to other causes. Of greatest consequence was the discarding of spiny dogfish that necessitates attention to gear modifications that might permit the escapement of these fish. What is surprising, is the general absence of consistent spatial and temporal effectors sustaining temporal and spatial stability in the pattern of discarding. Area-time management does not appear to be a hopeful approach to reduce discarding in these fisheries. In the one case where area-time management has been in force, for the *Loligo* squid fishery, inference suggests that forced reallocation of effort may well have resulted in increased discarding of some important species, thereby negating whatever benefits might have accrued for others.

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Legends for Tables

Table 1. Frequency of observed tows by month for each target species and the allocation of abutting months into Season bins, identified by same letters, for statistical analysis.

Table 2. Frequency of observed tows by two-hour time segments for each target species and the allocation of abutting time periods into Time-of-Day bins, identified by same letters, for statistical analysis. Hourly headers represent the central time of a two-hour interval.

Table 3. Frequency of observed tows by 20-m depth intervals for each target species and the allocation of abutting months into Depth bins, identified by same letters, for statistical analysis. Depth headers represent the central depth for a 20 m interval.

Table 4. Synopsis of observer data used for analysis.

Table 5. The frequency at which a species was designated a target in tows with up to 5 target species declared or inferred from 'Unknown' target designations and measured landings.

Table 6. Estimated distribution of small-mesh species landings reported in 2001 for 22 target species.

Table 7. Reported landings by trawl and dredge for 2001 (column 1), the volume of landings attributable to the directed fishery (column 2), and the estimated discards of species declared as targets in observed tows in the small-mesh fisheries in 2001. All values in kg.

Table 8. Estimated discards of selected species in all target fisheries for 2001. Totals are the sum of all discards for that species in all target fisheries. All values in kg.

Table 9. The number of tows in which a bycatch species was discarded for each target species. For example, in the case of *Illex* squid, 1,858 tows targeted cod. *Illex* squid was discarded on 145 of those tows.

Table 10. Reasons for discards for selected target species listed as the fraction of total discards for each target species: 1) Reason unknown; 2) No market, reason not specified; 3) Too small for market; 4) Quota for market filled; 5) Unable to maintain market quality during trip; 6) Regulatory, reason not specified; 7)

Below legal landing size; 8) Regulatory quota filled; 9) Catch in quota restricted area; 10) Retention not permitted; 11) Low quality, reason unknown; 12) Low quality, sandflea damage; 13) Low quality, gear damage; 14) Marine mammal caught; 15) Upgraded; 16) Market price too low; 17) Other.

Table 11. Results of ANCOVA tests evaluating the influence of season, time-of-day, depth, location, and fishing practices on discarding of selected species in the butterfish, *Loligo* squid, and silver hake fisheries. Analysis focused on the following target species-discard species pairs: *Loligo* squid-*Illex* squid, silver hake-silver hake, *Loligo* squid-silver hake, *Loligo* squid-butterfish, butterfish-butterfish, silver hake-butterfish, *Loligo* squid-spiny dogfish, silver hake-spiny dogfish, butterfish-spiny dogfish, butterfish-weakfish, *Loligo* squid-summer flounder, silver hake-summer flounder, butterfish-summer flounder, *Loligo* squid-*Loligo* squid, silver hake-*Loligo* squid, and butterfish-*Loligo* squid. –, $P > 0.05$. $*$, an interaction term.

Table 12. Species discards-to-target species landings ratios for butterfish, *Illex* squid, *Loligo* squid, summer flounder, silver hake, spiny dogfish, and weakfish discarded in butterfish-, *Loligo* squid-, and silver hake-targeted tows, by season. Distribution of observed tows by month is shown in Table 1.

Table 13. Species discards-to-target species landings ratios for butterfish, *Illex* squid, *Loligo* squid, summer flounder, silver hake, spiny dogfish, and weakfish discarded in butterfish-, *Loligo* squid-, and silver hake-targeted tows, by time-of-day. Distribution of observed tows by time-of-day is shown in Table 2.

Table 14. Species discards-to-target species landings ratios for butterfish, *Illex* squid, *Loligo* squid, summer flounder, silver hake, spiny dogfish, and weakfish discarded in butterfish-, *Loligo* squid-, and silver hake-targeted tows, by depth. Distribution of observed tows by depth is shown in Table 3.

Table 15. Species discards-to-target species landings ratios for butterfish, *Illex* squid, *Loligo* squid, summer flounder, silver hake, spiny dogfish, and weakfish discarded in butterfish-, *Loligo* squid-, and silver hake-targeted tows, by location.

Table 16. Contribution of discards of nine species to total commercial catch of the same nine species, based on 2001 landings (Table 7). Fraction of total discards (taken from Table 8) for each of the nine species occurring in the small-mesh fisheries (*Loligo* squid, butterfish, silver hake, Atlantic mackerel, and black sea bass).

Fraction of total discards for each of the nine species occurring in a three-species subset of the small-mesh fisheries (*Loligo* squid, butterfish, silver hake).

Table 1

Target Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Black Sea Bass	23	9	0	6	0	0	0	0	0	0	0	0
Butterfish	79	29	1	1	0	0	0	2	0	7	9	5
Loligo Squid	161	287	307	126	65	161	96	40	69	137	89	59
Atlantic Mackerel	17	27	29	34	10	0	0	0	0	0	0	0
Silver Hake	92	71	17	32	9	11	22	11	3	32	25	5
Season Bins												
Black Sea Bass	A	A	A	A	A	A	A	A	A	A	A	A
Butterfish	A	A	A	B	B	B	B	B	B	B	B	B
Loligo Squid	A	A	A	B	B	B	C	C	C	D	D	D
Atlantic Mackerel	A	A	A	B	B	B	B	B	B	B	B	B
Silver Hake	A	A	A	B	B	B	C	C	C	D	D	D

Table 2

Target Species	01:00	03:00	05:00	07:00	09:00	11:00	13:00	15:00	17:00	19:00	21:00	23:00
Black Sea Bass	2	3	0	9	4	2	6	1	5	2	3	1
Butterfish	5	2	5	20	22	18	13	11	14	10	9	4
Loligo Squid	20	19	21	265	206	253	215	215	192	105	60	26
Atlantic Mackerel	4	5	8	11	12	10	11	14	12	14	9	7
Silver Hake	5	6	11	53	56	49	46	37	22	16	16	13
Time-of-Day Bins												
Black Sea Bass	A	A	A	B	B	B	B	B	B	A	A	A
Butterfish	A	A	A	B	B	B	B	B	B	A	A	A
Loligo Squid	A	A	A	B	B	B	C	C	C	D	D	D
Atlantic Mackerel	A	A	A	B	B	B	B	B	B	A	A	A
Silver Hake	A	A	A	B	B	B	C	C	C	D	D	D

Table 3

Target Species	10	30	50	70	90	110	130	150	170	190	210	230	250	270	290	310	330	350
Black Sea Bass	2	21	9	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Butterfish	17	4	1	18	39	24	25	2	0	0	0	0	0	1	0	0	0	0
Loligo Squid	140	212	42	147	91	102	332	286	165	60	7	2	2	1	1	0	0	1
Atlantic Mackerel	6	9	39	13	14	15	4	12	5	0	0	0	0	0	0	0	0	0
Silver Hake	0	16	80	66	66	18	31	12	14	3	1	8	6	2	0	0	1	0

Depth Bins											
Black Sea Bass	A	A	A	A	A	A	A	A	A	A	→
Butterfish	A	A	A	B	B	B	C	C	C	C	→
Loligo Squid	A	A	A	B	B	B	C	C	C	D	→
Atlantic Mackerel	A	A	A	B	B	B	C	C	C	C	→
Silver Hake	A	A	A	B	B	B	C	C	C	D	→

Table 4

Target Species		Number of Boats	Number of Trips	Number of Tows
Cod	*Gadus morhua*	83	214	1,858
Haddock	*Melanogrammus aeglesinus*	41	62	823
Pollock	*Pollachius virens*	26	33	363
Redfish	*Sebastes* sp.	4	4	88
Loligo Squid	*Loligo pealei*	78	178	1,597
Illex Squid	*Illex illecebrosus*	15	32	269
Unknown Squid		1	1	1
Butterfish	*Peprilus triacanthus*	13	18	133
Red Hake	*Urophycis chuss*	4	4	26
Silver Hake	*Merluccius bilinearis*	37	66	330
White Hake	*Urophycis tenuis*	19	22	310
Scup	*Stenotomus chrysops*	19	29	116
Black Sea Bass	*Centropristis striata*	7	9	38
American Plaice	*Hippoglossoides platessoides*	63	122	1,630
Summer Flounder	*Paralichthys dentatus*	71	149	932
Witch Flounder	*Glyptocephalus cynoglossus*	62	127	1,337
Winter Flounder	*Pleuronectes americanus*	37	67	972
Windowpane Flounder	*Scophthalmus aquosus*	6	6	43
Yellowtail Flounder	*Pleuronectes ferrugineus*	50	106	619
Unknown Flounder		1	1	1
Atlantic Mackerel	*Scomber scombrus*	11	20	117
Atlantic Herring	*Clupea harengus*	5	9	17
Unknown Herring		1	1	4
Atlantic Croaker	*Micropogonias undulatus*	10	13	55
Spiny Dogfish	*Squalus acanthias*	7	10	33
Bluefish	*Pomatomus saltatrix*	2	2	4
Striped Bass	*Morone saxatilis*	2	2	4
Weakfish	*Cynoscion regalis*	7	13	44
Monkfish	*Lophius americanus*	58	93	1,515
Little Skate	*Leucoraja eriancea*	6	18	59
Winter Skate	*Leucoraja ocellata*	7	11	253
Unknown Skate		3	4	16
Horseshoe Crab	*Limulus polyphemus*	3	3	12
American Lobster	*Homarus americanus*	8	12	156
Sea Scallop	*Placopecten magellanicus*	32	75	4,826

Table 5

Target Species	Tows With 1 Target	Tows With 2 Targets	Tows With 3 Targets	Tows With 4 Targets	Tows With 5 Targets
Cod	387	301	367	298	505
Haddock	232	124	132	217	118
Pollock	26	11	21	106	199
Redfish	0	2	0	0	86
Loligo Squid	1,423	156	13	5	0
Illex Squid	269	0	0	0	0
Unknown Squid	1	0	0	0	0
Butterfish	76	45	12	0	0
Red Hake	0	6	0	20	0
Silver Hake	195	125	5	5	0
White Hake	1	11	7	140	151
Scup	89	4	23	0	0
Black Sea Bass	18	16	4	0	0
American Plaice	111	188	464	404	463
Summer Flounder	903	20	4	5	0
Witch Flounder	118	141	402	314	362
Winter Flounder	286	234	267	56	129
Windowpane Flounder	0	6	0	37	0
Yellowtail Flounder	280	191	69	45	34
Unknown Flounder	1	0	0	0	0
Atlantic Mackerel	112	5	0	0	0
Atlantic Herring	12	5	0	0	0
Unknown Herring	4	0	0	0	0
Atlantic Croaker	55	0	0	0	0
Spiny Dogfish	31	2	0	0	0
Bluefish	0	0	4	0	0
Striped Bass	4	0	0	0	0
Weakfish	42	2	0	0	0
Monkfish	348	108	310	356	393
Little Skate	42	12	5	0	0
Winter Skate	2	9	126	36	80
Unknown Skate	16	0	0	0	0
Horseshoe Crab	12	0	0	0	0
American Lobster	12	40	24	0	80
Sea Scallop	4,826	0	0	0	0

Table 6

Target Species	*Loligo* Fishery	Atlantic Mackerel Fishery	Silver Hake Fishery	Black Sea Bass Fishery	Butterfish Fishery
Cod	1,533	3,545	41,160	0	0
Haddock	48	1,830	162	28	9
Pollock	1	1	39	0	0
Loligo Squid	11,395,062	96,485	1,074,566	38,563	266,519
Illex Squid	8,631	0	2	0	3,401
Butterfish	1,020,149	13,268	1,726,831	114,318	3,591,062
Silver Hake	1,149,926	28,817	9,604,652	59,670	316,463
White Hake	0	35	1,656	0	0
Scup	66,567	188	65,725	101,685	22,351
Black Sea Bass	11,550	0	29,999	247,742	3,341
American Plaice†	0	0	0	0	0
Summer Flounder	56,288	2,065	285,644	42,956	40,416
Witch Flounder†	0	0	0	0	0
Winter Flounder	4,435	20	1,942	1,843	294
Yellowtail Flounder	3,054	265	4,766	143	0
Atlantic Mackerel	28,370	11,800,249	27,583	1,020	11,607
Atlantic Croaker	2,784	0	0	0	14,446
Spiny Dogfish†	0	0	0	0	0
Weakfish	69	0	0	181	5,239
Monkfish	5,045	460	39,710	0	0
American Lobster†	0	0	0	0	0
Sea Scallop	90	53	934	4,018	0

†Zero landings estimates for spiny dogfish, American lobster, American plaice, and witch flounder represent cases where the total yearly reported landings were not sufficient to account for the estimated landings from all bycatch sources [equation (1)], rather than the absence of selected target-species landings in these directed fisheries.

Table 7

Species	Reported Landings	Estimated Directed Fishery Landings	Estimated 2001 Discards: *Loligo* Squid Fishery	Atlantic Mackerel Fishery	Silver Hake Fishery	Black Sea Bass Fishery	Butterfish Fishery
Cod	9,615,028	4,711,683	467	0	26,927	0	483
Haddock	5,498,353	2,368,582	2,119	0	1,789	0	0
Pollock	2,168,291	33,135	246	0	10,673	0	0
Loligo Squid	13,751,128	11,395,062	348,107	2,411	309,551	14	306,209
Illex Squid	605,613	296,597	231,052	1,204	73,296	55	21,204
Butterfish	4,279,484	3,591,062	1,852,318	77,184	962,315	83	2,518,928
Silver Hake	12,895,224	9,604,652	1,676,080	4,731	2,075,170	0	292,975
White Hake	2,483,675	310,189	70,097	0	28,250	0	1,639
Scup	1,175,658	799,158	153,831	12,715	105,331	271,046	419,563
Black Sea Bass	610,713	247,742	47,629	1,144	69,973	64,143	43,037
American Plaice	4,478,400	0	192	0	25,446	0	819
Summer Flounder	4,872,549	3,946,749	241,198	1,483	609,460	55,686	309,577
Witch Flounder	2,956,011	0	25,359	52	34,199	12,390	7,633
Winter Flounder	6,587,961	4,189,552	24,696	0	48,943	0	6,591
Yellowtail Flounder	6,977,671	5,387,876	10,882	0	10,510	0	1,862
Atlantic Mackerel	11,948,927	11,800,249	242,018	133,403	126,047	0	1,565
Atlantic Croaker	3,908,141	3,888,822	0	0	0	0	0
Spiny Dogfish	250,927	0	603,788	111,648	2,035,012	78,252	1,999,371
Weakfish	535,591	142,243	684	73	741	0	187,607
Monkfish	15,133,534	10,668,559	150,750	38	377,439	51,062	33,996
American Lobster	319,398	0	10,314	41	66,932	83	9,772
Sea Scallop	23,551,592	23,271,750	95,841	35	55,582	14,464	124,836
Total			5,787,668	346,162	7,053,586	547,278	6,287,667

Table 8

Target Species	*Loligo* Squid	*Illex* Squid	Silver Hake	Atlantic Mackerel	Butterfish	Summer Flounder	Spiny Dogfish	Weakfish	Monkfish
	Discarded Species								
Cod	1,079	5,024	72,871	1,943	125	5,128	769,901	0	196,333
Haddock	98	615	14,117	986	16	1,692	144,713	0	50,921
Pollock	40	48	539	7	1	0	4,788	0	1,361
Loligo Squid	348,107	231,051	1,676,080	242,018	1,852,318	241,198	603,788	685	150,750
Illex Squid	47	2,232	511	1	7,512	0	34	0	45
Butterfish	306,209	21,204	292,975	1,565	2,518,928	309,577	1,999,371	187,607	33,996
Silver Hake	309,552	73,296	2,075,170	126,047	962,315	609,460	2,035,012	741	377,439
White Hake	15	647	42,325	89	0	0	69,478	20	88,161
Scup	7,113	67	8,853	22,444	31,642	43,351	206,507	188	26,111
Black Sea Bass	14	55	0	0	83	55,685	78,252	0	51,062
Summer Flounder	20,777	2,617	35,544	1,198	150,492	214,908	466,879	941	48,787
Winter Flounder	1,175	5,037	18,799	274	1,991	48,522	317,534	0	42,235
Yellowtail Flounder	3,476	6,000	25,785	1,524	1,337	105,716	282,312	0	69,765
Atlantic Mackerel	2,410	1,204	4,732	133,403	77,184	1,483	111,648	73	38
Atlantic Croaker	371	0	0	0	1,119	43,362	30,631	179,137	0
Weakfish	0	0	0	0	578	3,706	173	15,291	0
Monkfish	2,255	11,091	523,386	1,488	48,769	7,890	931,494	28	1,557,088
Sea Scallop[1]	5,480	723	7,670	120	215	287,533	67,794	27	426,711
Total	1,008,220	360,913	4,799,358	533,107	5,654,623	1,979,213	8,120,311	384,737	3,118,805

[1]Discards in the scallop fishery are based on a subset of observer reports for the geographic region between Cape Hatteras and Block Island, New York and, therefore, represent minimal values.

Table 9

Illex Squid

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	145	0	0	0.0000
Haddock	823	67	0	0	0.0000
Pollock	363	30	0	0	0.0000
Loligo Squid	1,597	519	32	1	0.0207
Illex Squid	269	58	15	2	0.0632
Butterfish	133	27	0	0	0.0000
Silver Hake	330	58	2	0	0.0061
White Hake	310	24	0	0	0.0000
Scup	116	3	1	0	0.0086
Black Sea Bass	38	1	0	0	0.0000
Summer Flounder	932	13	0	0	0.0000
Winter Flounder	972	111	0	0	0.0000
Yellowtail Flounder	619	22	0	0	0.0000
Atlantic Mackerel	117	18	0	0	0.0000
Atlantic Croaker	55	0	0	0	0.0000
Weakfish	44	0	0	0	0.0000
Monkfish	1,515	134	0	0	0.0000
Sea Scallop	4,826	58	0	0	0.0000

Silver Hake

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	741	0	0	0.0000
Haddock	823	360	0	0	0.0000
Pollock	363	171	0	0	0.0000
Loligo Squid	1,597	741	200	28	0.1428
Illex Squid	269	76	1	1	0.0074
Butterfish	133	90	1	0	0.0075
Silver Hake	330	154	38	13	0.1545
White Hake	310	157	0	0	0.0000
Scup	116	40	0	0	0.0000
Black Sea Bass	38	0	0	0	0.0000
Summer Flounder	932	57	4	0	0.0043
Winter Flounder	972	253	0	0	0.0000
Yellowtail Flounder	619	116	0	0	0.0000
Atlantic Mackerel	117	41	1	0	0.0085
Atlantic Croaker	55	0	0	0	0.0000
Weakfish	44	0	0	0	0.0000
Monkfish	1,515	826	7	0	0.0046
Sea Scallop	4,826	413	0	0	0.0000

Butterfish

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	9	0	0	0.0000
Haddock	823	4	0	0	0.0000
Pollock	363	2	0	0	0.0000
Loligo Squid	1,597	1,109	141	26	0.1046
Illex Squid	269	42	13	8	0.0781
Butterfish	133	115	36	1	0.2782
Silver Hake	330	198	29	1	0.0909
White Hake	310	0	0	0	0.0000
Scup	116	47	6	0	0.0517
Black Sea Bass	38	3	0	0	0.0000
Summer Flounder	932	85	17	1	0.0193
Winter Flounder	972	37	0	0	0.0000
Yellowtail Flounder	619	16	0	0	0.0000
Atlantic Mackerel	117	49	13	4	0.1453
Atlantic Croaker	55	6	0	0	0.0000
Weakfish	44	20	0	0	0.0000
Monkfish	1,515	21	1	0	0.0007
Sea Scallop	4,826	22	0	0	0.0000

Spiny Dogfish

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	773	28	2	0.0161
Haddock	823	273	12	0	0.0146
Pollock	363	185	2	0	0.0055
Loligo Squid	1,597	402	75	6	0.0507
Illex Squid	269	52	0	0	0.0000
Butterfish	133	54	17	4	0.1579
Silver Hake	330	175	30	4	0.1030
White Hake	310	88	1	0	0.0032
Scup	116	59	12	3	0.1293
Black Sea Bass	38	22	3	0	0.0789
Summer Flounder	932	349	51	2	0.0569
Winter Flounder	972	307	11	0	0.0113
Yellowtail Flounder	619	156	10	0	0.0162
Atlantic Mackerel	117	62	19	3	0.1880
Atlantic Croaker	55	23	0	0	0.0000
Weakfish	44	2	0	0	0.0000
Monkfish	1,515	616	12	0	0.0079
Sea Scallop	4,826	582	0	0	0.0000

Weakfish

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	0	0	0	0.0000
Haddock	823	0	0	0	0.0000
Pollock	363	0	0	0	0.0000
Loligo Squid	1,597	19	0	0	0.0000
Illex Squid	269	0	0	0	0.0000
Butterfish	133	6	3	0	0.0226
Silver Hake	330	4	0	0	0.0000
White Hake	310	1	0	0	0.0000
Scup	116	4	0	0	0.0000
Black Sea Bass	38	0	0	0	0.0000
Summer Flounder	932	46	0	0	0.0000
Winter Flounder	972	0	0	0	0.0000
Yellowtail Flounder	619	0	0	0	0.0000
Atlantic Mackerel	117	5	0	0	0.0000
Atlantic Croaker	55	32	6	1	0.1273
Weakfish	44	21	3	0	0.0682
Monkfish	1,515	1	0	0	0.0000
Sea Scallop	4,826	1	0	0	0.0000

Summer Flounder

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	40	0	0	0.0000
Haddock	823	17	0	0	0.0000
Pollock	363	0	0	0	0.0000
Loligo Squid	1,597	500	51	0	0.0319
Illex Squid	269	0	0	0	0.0000
Butterfish	133	78	2	0	0.0150
Silver Hake	330	113	33	0	0.1000
White Hake	310	0	0	0	0.0000
Scup	116	66	5	0	0.0431
Black Sea Bass	38	23	3	0	0.0789
Summer Flounder	932	712	12	0	0.0129
Winter Flounder	972	125	0	0	0.0000
Yellowtail Flounder	619	101	3	0	0.0048
Atlantic Mackerel	117	18	0	0	0.0000
Atlantic Croaker	55	37	0	0	0.0000
Weakfish	44	15	0	0	0.0000
Monkfish	1,515	8	0	0	0.0000
Sea Scallop	4,826	2,130	1	0	0.0002

Loligo Squid

Target Species	Number of Tows Targeted	Number of Tows Discarded	Number of Tows >100 kg Discards	Number of Tows >1,000 kg Discarded	Fraction of Tows >100 kg Discarded
Cod	1,858	52	0	0	0.0000
Haddock	823	19	0	0	0.0000
Pollock	363	14	0	0	0.0000
Loligo Squid	1,597	621	51	3	0.0338
Illex Squid	269	16	0	0	0.0000
Butterfish	133	95	5	0	0.0376
Silver Hake	330	102	15	0	0.0455
White Hake	310	2	0	0	0.0000
Scup	116	35	0	0	0.0000
Black Sea Bass	38	1	0	0	0.0000
Summer Flounder	932	104	2	0	0.0021
Winter Flounder	972	51	0	0	0.0000
Yellowtail Flounder	619	29	0	0	0.0000
Atlantic Mackerel	117	45	0	0	0.0000
Atlantic Croaker	55	5	0	0	0.0000
Weakfish	44	0	0	0	0.0000
Monkfish	1,515	47	0	0	0.0000
Sea Scallop	4,826	301	0	0	0.0000

Table 10

Target Species / Bycatch Species	Reason for Discard 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Loligo Squid																	
Loligo Squid	0.0094	0.0131	0.7688	0.0000	0.0000	0.0000	0.0040	0.0000	0.0000	0.0000	0.0414	0.0003	0.0000	0.0000	0.0000	0.0000	0.1630
Illex Squid	0.0028	0.8148	0.1065	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0745
Butterfish	0.0011	0.3895	0.5863	0.0000	0.0000	0.0000	0.0213	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0017
Silver Hake	0.0067	0.7295	0.1950	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0313	0.0003	0.0000	0.0000	0.0000	0.0000	0.0370
Summer Flounder	0.0027	0.0055	0.1512	0.0030	0.0008	0.0082	0.0060	0.3190	0.0013	0.0014	0.0000	0.0000	0.0000	0.0011	0.0001	0.1545	0.2917
Spiny Dogfish	0.0000	0.3778	0.0681	0.0000	0.0000	0.0764	0.0001	0.0000	0.0108	0.2547	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2121
Weakfish	0.0373	0.6169	0.2289	0.0000	0.0000	0.0560	0.0608	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Silver Hake																	
Loligo Squid	0.0294	0.1747	0.6408	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.1518
Illex Squid	0.0000	0.9890	0.0044	0.0000	0.0000	0.0000	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0053
Butterfish	0.0007	0.0248	0.9632	0.0000	0.0000	0.0000	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0084
Silver Hake	0.0000	0.2258	0.7095	0.0000	0.0000	0.0000	0.0509	0.0000	0.0000	0.0000	0.0074	0.0000	0.0002	0.0000	0.0000	0.0000	0.0062
Summer Flounder	0.0000	0.0000	0.2919	0.0000	0.0000	0.0002	0.0080	0.1078	0.0055	0.0000	0.0056	0.0000	0.0000	0.0000	0.0000	0.0651	0.5160
Spiny Dogfish	0.0002	0.7227	0.1567	0.0000	0.0000	0.0200	0.0010	0.0016	0.0018	0.0960	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Weakfish	0.0000	0.1737	0.7179	0.0000	0.0000	0.0000	0.1084	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Butterfish																	
Loligo Squid	0.0010	0.1095	0.6408	0.0000	0.0000	0.0000	0.0754	0.0000	0.0000	0.0000	0.1221	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Illex Squid	0.0000	0.9965	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0035
Butterfish	0.0012	0.0580	0.9269	0.0000	0.0000	0.0000	0.0139	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Silver Hake	0.0000	0.1450	0.8454	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Summer Flounder	0.0043	0.0000	0.0000	0.0000	0.0000	0.0861	0.1603	0.3826	0.0000	0.0048	0.0000	0.0000	0.0000	0.0000	0.0083	0.3122	0.0413
Spiny Dogfish	0.0000	0.9894	0.0021	0.0000	0.0000	0.0060	0.0000	0.0000	0.0007	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Weakfish	0.0000	0.0000	0.9925	0.0000	0.0000	0.0000	0.0075	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 11

Directed Fishery	Butterfish Discards	*Illex* Squid Discards	Silver Hake Discards	Spiny Dogfish Discards	Summer Flounder Discards	Weakfish Discards	*Loligo* Squid Discards
Butterfish							
Season	–	–	$P = 0.07$	–	–	$P < 0.0001$	–
Time-of-Day	–	$P = 0.05$	–	–	–	–	–
Depth	–	$P = 0.0072$	$P = 0.0058$	–	–	$P < 0.0001$	–
Location	–	–	–	$P = 0.0135$	–	$P < 0.0001$	$P < 0.0001$
Codend Mesh	–	$P = 0.0042$	–	–	$P = 0.017$	$P < 0.0001$	–
Effort	–		–	–	–	–	–
Total Catch	$P < 0.0001$		$P < 0.0001$	$P = 0.0042$	–	$P = 0.014$	–
Depth*Location	–	–	–	–	$P = 0.0036$	$P = 0.0007$	–
Loligo Squid							
Season	$P = 0.028$	$P = 0.005$	–	$P = 0.0024$	–	–	$P = 0.0002$
Time-of-Day	–	$P = 0.0029$	$P = 0.05$	–	–	–	–
Depth	$P = 0.021$	$P < 0.0001$	$P = 0.0034$	–	–	$P = 0.0067$	–
Location	$P < 0.0001$	$P = 0.0006$	$P < 0.0001$	–	$P < 0.0001$	$P < 0.0001$	$P = 0.0003$
Codend Mesh	$P < 0.0001$	–	$P = 0.0009$	–	$P < 0.0001$	–	$P < 0.0001$
Effort	$P = 0.0023$	–	–	–	–	–	$P < 0.0001$
Total Catch	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P = 0.0002$	$P < 0.0001$	–	$P < 0.0001$
Season*Depth	$P < 0.0001$	$P < 0.0001$	$P = 0.0012$	$P = 0.008$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Season*Location	$P < 0.0001$	$P = 0.01$	$P < 0.0001$	$P < 0.0001$	$P = 0.011$	$P < 0.0001$	$P < 0.0001$
Depth*Location	$P = 0.0003$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P = 0.0005$	$P < 0.0001$	$P < 0.0001$
Silver Hake							
Season	–	$P < 0.0001$	$P < 0.0001$	$P = 0.0003$	$P = 0.004$	–	$P = 0.011$
Time-of-Day	–	–	–	–	–	–	$P < 0.0001$
Depth	$P = 0.0089$	$P = 0.0004$	–	–	$P = 0.0021$	–	$P = 0.011$
Location	$P = 0.011$	$P = 0.0007$	$P < 0.0001$	–	$P = 0.046$	–	$P < 0.0001$
Codend Mesh	$P = 0.0004$	–	$P = 0.0019$	–	$P < 0.0001$	–	$P < 0.0001$
Effort	–	–	–	$P = 0.045$	–	–	$P = 0.05$
Total Catch	$P = 0.028$	–	–	$P < 0.0001$	$P = 0.0002$	–	–
Season*Depth	–	–	–	–	$P = 0.05$	–	–
Season*Location	$P = 0.022$	–	$P = 0.0002$	–	–	–	–
Depth*Location	–	$P = 0.0058$	–	$P = 0.011$	$P = 0.036$	$P = 0.05$	$P < 0.0001$

Table 12

Target Species / Discard Species	Jan-Mar	Apr-Dec
Butterfish (N =)	106	18
Butterfish	3.0920	0.4184
Illex Squid	0.0458	0.0011
Loligo Squid	1.7930	0.0000
Silver Hake	1.1520	0.2222
Spiny Dogfish	3.8580	0.2324
Summer Flounder	0.8933	0.0832
Weakfish	0.0000	0.2817

	Jan-Mar	Apr-May	Jun-Sep	Oct-Dec
Loligo Squid (N =)	746	344	197	282
Butterfish	0.5797	0.7955	0.2014	0.5283
Illex Squid	0.0333	0.0241	0.0016	0.0023
Loligo Squid	0.1346	0.0465	0.1332	0.0320
Silver Hake	0.4654	0.1310	0.0989	0.1909
Spiny Dogfish	0.7068	0.1421	0.0345	0.3966
Summer Flounder	0.6212	0.4982	0.0265	0.0090
Weakfish	0.0016	0.0004	0.0001	0.0029
Silver Hake (N =)	170	52	35	60
Butterfish	1.9590	0.5406	0.1555	0.0170
Illex Squid	0.9017	0.0006	0.0055	0.0000
Loligo Squid	0.2363	0.0746	0.0001	0.0002
Silver Hake	0.1382	0.0449	0.9685	0.0985
Spiny Dogfish	2.3390	0.0739	0.0250	0.5146
Summer Flounder	0.3045	0.6657	0.0000	0.0001
Weakfish	0.0033	0.0000	0.0000	0.0000

Table 13

Target Species / Discard Species	1800-0600	0600-1800
Butterfish (N =)	35	89
Butterfish	2.6730	2.7160
Illex Squid	0.0150	0.0488
Loligo Squid	1.9720	1.3600
Silver Hake	1.5560	0.8051
Spiny Dogfish	4.8010	2.7540
Summer Flounder	0.5220	0.8755
Weakfish	0.0000	0.0570

	0000-0600	0600-1200	1200-1800	1800-2400
Loligo Squid (N =)	60	712	611	186
Butterfish	0.8452	0.4908	0.6110	0.6519
Illex Squid	0.0130	0.0218	0.0232	0.0192
Loligo Squid	0.1487	0.1157	0.0744	0.0803
Silver Hake	0.8360	0.1847	0.2209	0.8008
Spiny Dogfish	1.0410	0.3322	0.4427	0.6738
Summer Flounder	0.9577	0.2855	0.5023	0.4031
Weakfish	0.0013	0.0022	0.0008	0.0004
Silver Hake (N =)	22	152	99	44
Butterfish	0.0467	0.2391	3.2890	0.1051
Illex Squid	0.0034	0.2562	1.1520	0.0098
Loligo Squid	0.0008	0.0853	0.2832	0.0694
Silver Hake	0.2473	0.2120	0.1656	0.2633
Spiny Dogfish	0.1195	0.2580	3.9220	0.0728
Summer Flounder	0.0238	0.1904	0.4575	0.2640
Weakfish	0.0000	0.0016	0.0033	0.0000

Table 14

Target Species / Discard Species	0-60 m	60-120 m	120-180 m
Butterfish (N =)	17	79	27
Butterfish	0.3940	3.2420	2.0660
Illex Squid	0.0012	0.0271	0.1005
Loligo Squid	0.0000	1.5800	2.4130
Silver Hake	0.2353	1.0040	1.5470
Spiny Dogfish	0.2424	5.0600	0.3455
Summer Flounder	0.0791	0.8861	0.7657
Weakfish	0.2982	0.0000	0.0000

	0-60 m	60-120 m	120-180 m	180- m
Loligo Squid (N =)	385	336	774	68
Butterfish	0.2258	1.7304	0.2731	0.0529
Illex Squid	0.0026	0.0097	0.0325	0.0681
Loligo Squid	0.0733	0.2288	0.0508	0.0749
Silver Hake	0.0186	0.6335	0.2984	0.2083
Spiny Dogfish	0.6259	1.0990	0.1037	0.0631
Summer Flounder	0.0313	1.7310	0.0276	0.0207
Weakfish	0.0021	0.0017	0.0005	0.0009
Silver Hake (N =)	93	149	50	19
Butterfish	0.0702	0.3810	6.0610	0.0019
Illex Squid	0.0085	0.0019	3.0390	0.0252
Loligo Squid	0.0450	0.0908	0.4844	0.0808
Silver Hake	0.3699	0.2022	0.0182	0.0000
Spiny Dogfish	4.1610	0.2745	0.0666	0.0374
Summer Flounder	0.0006	0.4480	0.2157	0.1053
Weakfish	0.0045	0.0001	0.0001	0.0002

Table 15

Target/Discard Sspecies	Delaware Bay South	Delaware Bay to Hudson Canyon	Hudson Canyon to Block Island	Block Island East
Butterfish (N =)	8	20	73	23
Butterfish	0.1954	6.8610	2.3150	1.1940
Illex Squid	0.0000	0.0481	0.0046	0.1555
Loligo Squid	0.0000	7.2150	0.5492	0.2458
Silver Hake	0.0000	4.1340	0.4893	0.3353
Spiny Dogfish	0.0000	0.0015	5.1220	1.7040
Summer Flounder	0.0451	0.8581	0.7935	0.9017
Weakfish	0.3415	0.0000	0.0320	0.0000

	Cape Hatteras to Chesapeake Bay	Chesapeake Bay to Delaware Bay	Delware Bay to Hudson Canyon	Hudson Canyon to Block Island	Block Island to Cape Cod	Georges Bank West	Georges Bank East
Loligo Squid (N =)	8	111	241	515	499	75	102
Butterfish	0.9773	0.2526	0.2169	0.5705	0.9582	0.1252	0.2026
Illex Squid	0.0237	0.0196	0.0148	0.0179	0.0323	0.0165	0.0036
Loligo Squid	0.0455	0.0005	0.0251	0.0882	0.1818	0.0106	0.0212
Silver Hake	0.0000	0.0048	0.1026	0.1255	0.3094	0.3522	1.9090
Spiny Dogfish	0.0000	0.0241	0.9642	0.1603	0.7242	0.0511	0.0348
Summer Flounder	0.0000	0.0085	0.0140	0.1333	1.1280	0.0330	0.0005
Weakfish	0.0000	0.0002	0.0003	0.0015	0.0017	0.0000	0.0000

	Hudson Canyon South	Hudson Canyon to Block Island	Block Island to Cape Cod	Georges Bank	Gulf of Maine
Silver Hake (N =)	52	93	74	76	15
Butterfish	0.0449	3.5830	0.4147	0.0025	0.0396
Illex Squid	0.7995	1.1990	0.0058	0.0000	0.0007
Loligo Squid	0.0000	0.3911	0.0980	0.0002	0.0087
Silver Hake	0.0580	0.0123	0.6825	0.1397	0.0071
Spiny Dogfish	1.4470	0.1111	4.5010	0.1866	0.0031
Summer Flounder	0.0153	0.5251	0.4933	0.0001	0.0000
Weakfish	0.0014	0.0016	0.0043	0.0000	0.0000

Table 16

Discarded Species†	Discards as a Fraction of Total Landings + Discards	Fraction of Discards in Small-Mesh Fisheries	Fraction of Discards in *Loligo* Squid, Silver Hake and Butterfish Fisheries
Loligo Squid	0.068	0.958	0.956
Illex Squid	0.373	0.906	0.902
Silver Hake	0.271	0.844	0.843
Atalantic Mackerel	0.043	0.944	0.693
Butterfish	0.569	0.957	0.943
Summer Flounder‡	0.289	0.615	0.586
Spiny Dogfish	0.970	0.595	0.571
Weakfish	0.418	0.492	0.491
Monkfish	0.171	0.197	0.180

†Discards and landings do not include the recreational fishery. ‡Discards are minimal estimates because the analysis is based on only a subset of sea-scallop dredge hauls.

Legends for Figures

Figure 1. The location of tows in which silver hake, butterfish, *Loligo* squid, summer flounder, *Illex* squid, and spiny dogfish were discarded in *Loligo*-targeted tows for those tows characterized by a high (A) or low (B) level of discarding. A) The larger symbol represents tows with discarding of silver hake, butterfish, *Loligo* squid, *Illex* squid, or spiny dogfish in the range >1,000 kg tow^{-1} and for summer flounder, in the range of >100 kg tow^{-1}; the smaller symbol, tows in the range >100-1,000 kg tow^{-1}, except for summer flounder in the range of >10-100 kg tow^{-1}. B) The larger symbol represents tows with discarding of silver hake, butterfish, *Loligo* squid, *Illex* squid, or spiny dogfish in the range >10-100 kg tow^{-1} and for summer flounder, in the range of >1-10 kg tow^{-1}; the smaller symbol, tows in the range >1-10 kg tow^{-1}, except for summer flounder in the range of >0.1-1 kg tow^{-1}. See Figure 2 for legend.

Figure 2. The location of tows in which silver hake, butterfish, *Loligo* squid, summer flounder, and spiny dogfish were discarded in silver hake-targeted tows for those tows characterized by a high (A) or low (B) level of discarding. A) The larger symbol represents tows with discarding of silver hake, butterfish, or spiny dogfish in the range >1,000 kg tow^{-1} and for *Loligo* squid and summer flounder, in the range of >100 kg tow^{-1}; the smaller symbol, tows in the range >100-1,000 kg tow^{-1}, except for *Loligo* squid and summer flounder in the range of >10-100 kg tow^{-1}. B) The larger symbol represents tows with discarding of silver hake, butterfish, or spiny dogfish in the range >10-100 kg tow^{-1} and for *Loligo* squid and summer flounder, in the range of >1-10 kg tow^{-1}; the smaller symbol, tows in the range >1-10 kg tow^{-1}, except for *Loligo* squid and summer flounder in the range of >0.1-1 kg tow^{-1}.

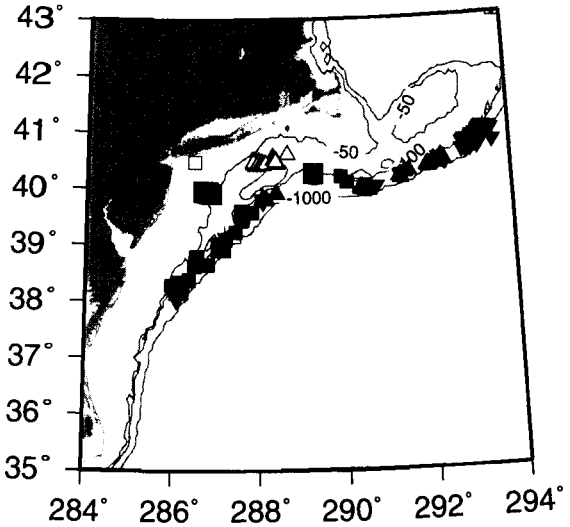
Figure 3. The location of tows in which butterfish, *Loligo* squid, summer flounder, spiny dogfish, and weakfish were discarded in butterfish-targeted tows for those tows characterized by a high (A) or low (B) level of discarding. A) The larger symbol represents tows with discarding of butterfish and spiny dogfish in the range >1,000 kg tow^{-1} and for *Loligo* squid, summer flounder and weakfish, in the range of >100 kg tow^{-1}; the smaller symbol, tows in the range >100-1,000 kg tow^{-1}, except for summer flounder, *Loligo* squid, and weakfish in the range of >10-100 kg tow^{-1}. B) The larger symbol represents tows with discarding of butterfish and spiny dogfish in the range >10-100 kg tow^{-1} and for summer flounder, *Loligo* squid and weakfish, in the range of >1-10 kg tow^{-1}; the smaller symbol, tows in the range >1-10 kg tow^{-1}, except for summer flounder, *Loligo* squid and weakfish in the range of >0.1-1 kg tow^{-1}.

Figure 4. Correlograms obtained from the spatial-temporal pattern of discarding of selected species in selected fisheries as measured by Geary's C. Correlogram values were calculated for time and distance steps of 30 days and 18.533 km (=10 minutes of latitude).

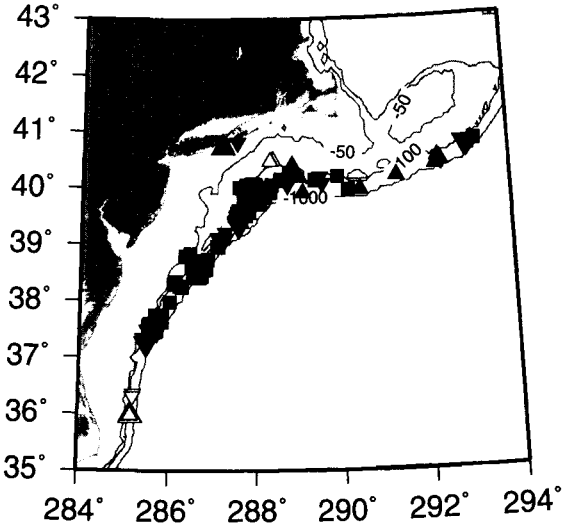
Figure 5. Plot of the incidence of large (>100 kg tow^{-1}) discarding events against species

discards-to-target species landings ratios for ten target species-discard species pairs distributed three in the *Loligo* fishery – silver hake, *Illex* squid, and butterfish; four in the silver hake fishery – spiny dogfish, silver hake, butterfish, and summer flounder; and three in the butterfish fishery – weakfish, spiny dogfish, and butterfish.

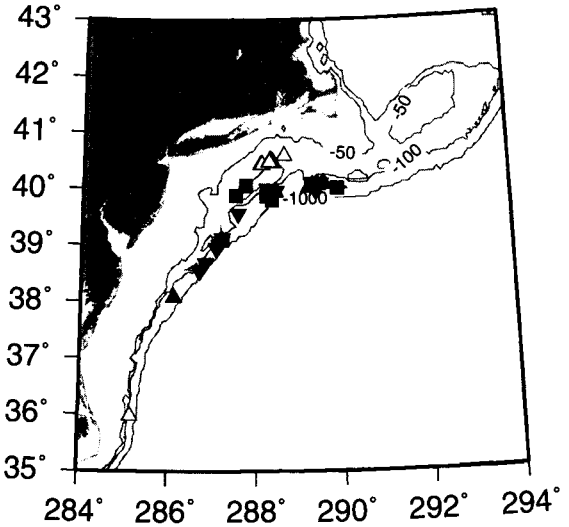
Target: Loligo Squid
Bycatch: Silver Hake



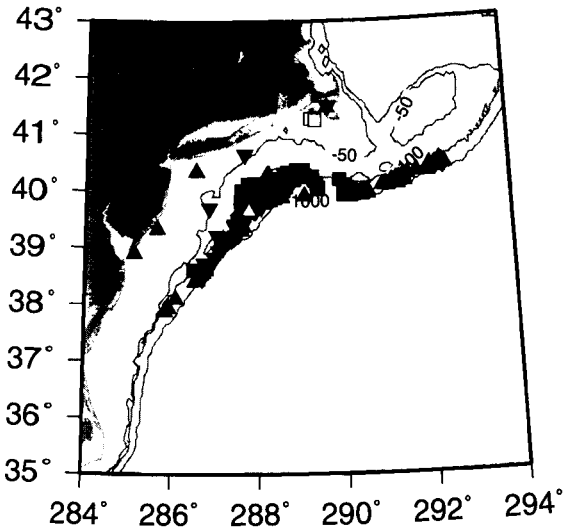
Target: Loligo Squid
Bycatch: Butterfish



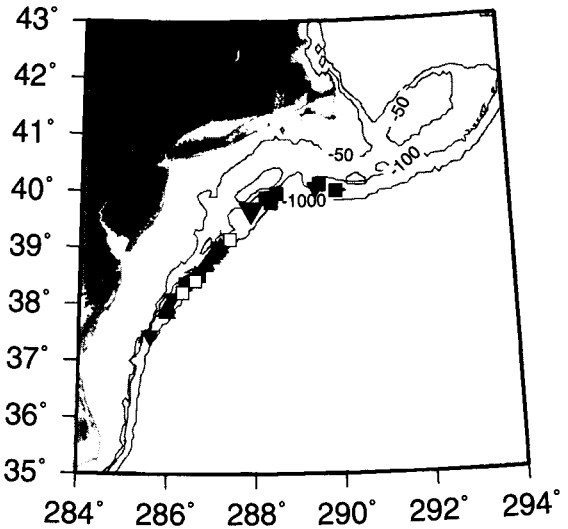
Target: Loligo Squid
Bycatch: Loligo Squid



Target: Loligo Squid
Bycatch: Summer Flounder



Target: Loligo Squid
Bycatch: Illex Squid



Target: Loligo Squid
Bycatch: Spiny Dogfish

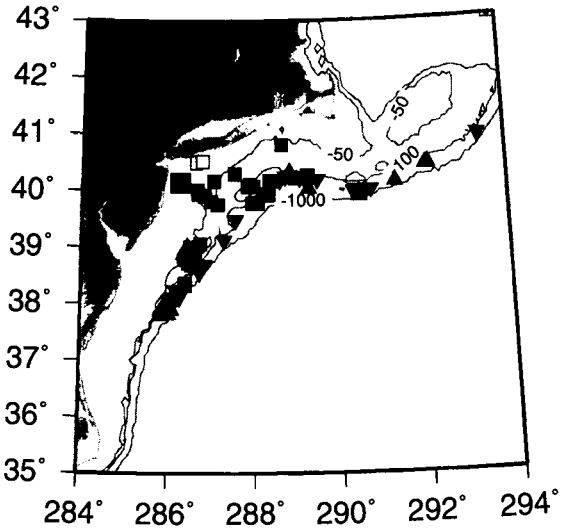
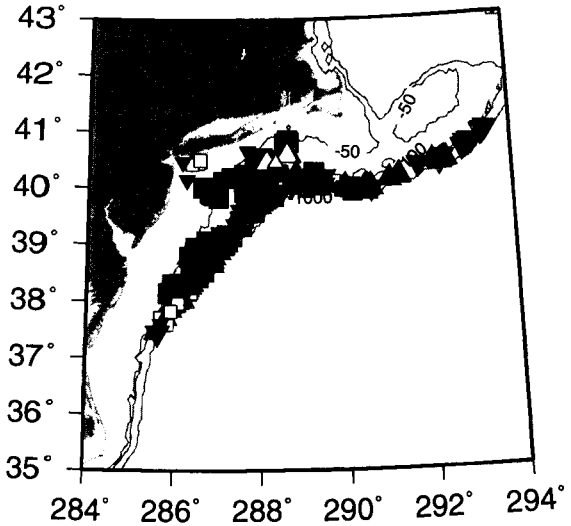
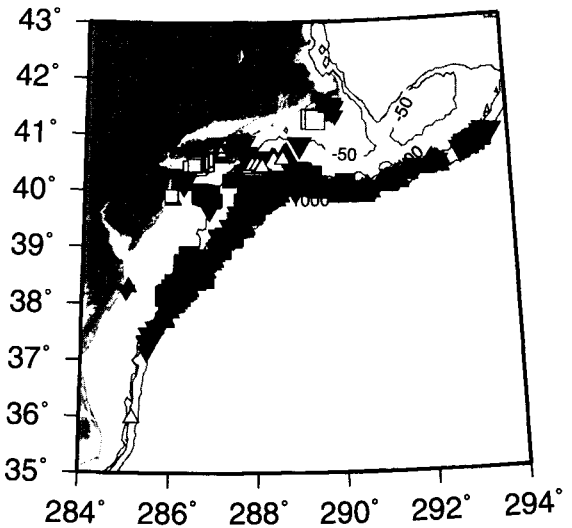


Figure 1a

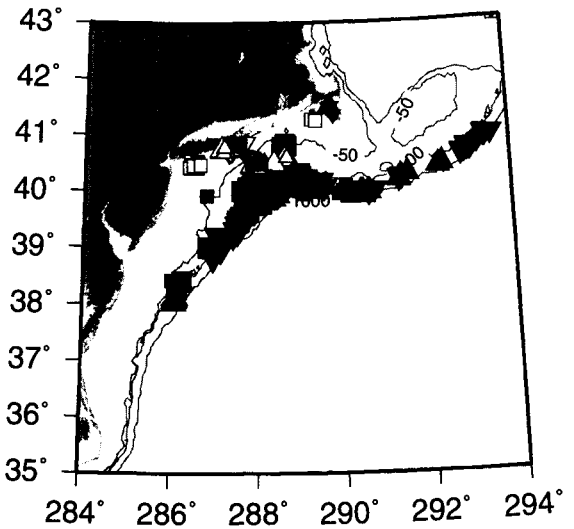
Target: Loligo Squid
Bycatch: Silver Hake



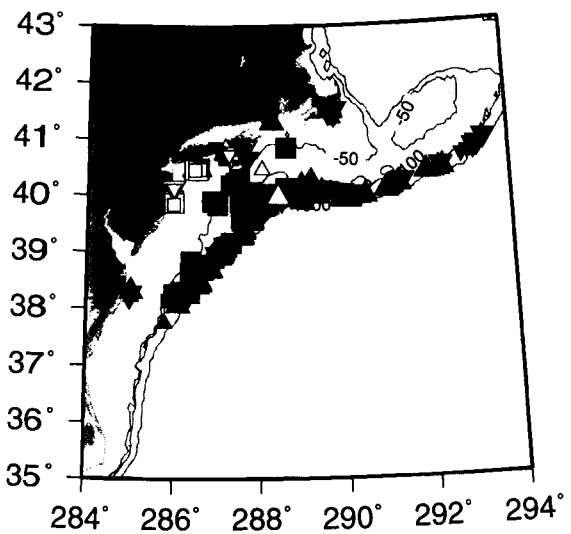
Target: Loligo Squid
Bycatch: Butterfish



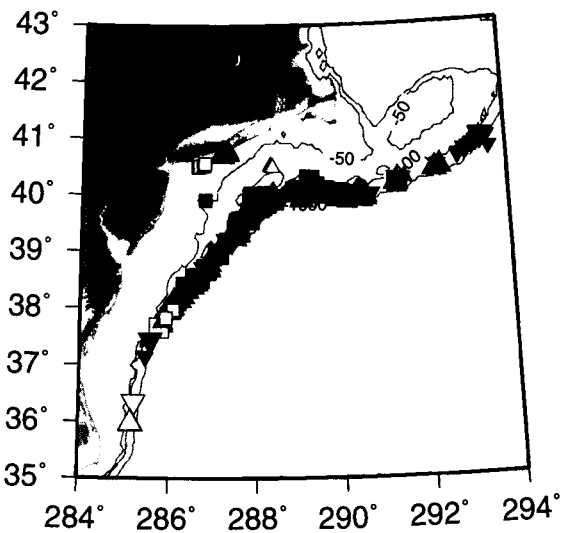
Target: Loligo Squid
Bycatch: Loligo Squid



Target: Loligo Squid
Bycatch: Summer Flounder



Target: Loligo Squid
Bycatch: Illex Squid



Target: Loligo Squid
Bycatch: Spiny Dogfish

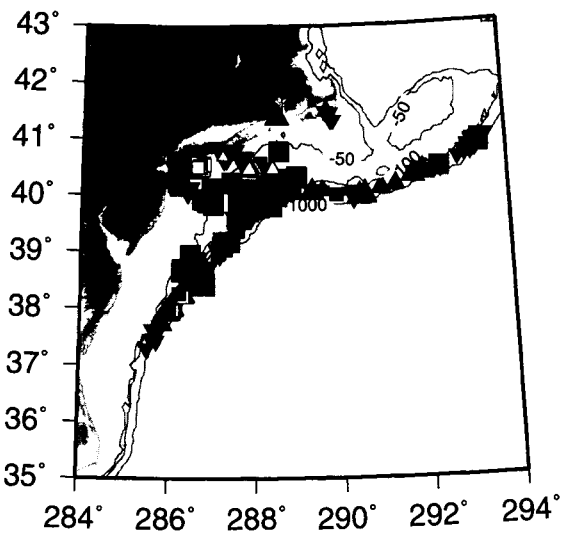
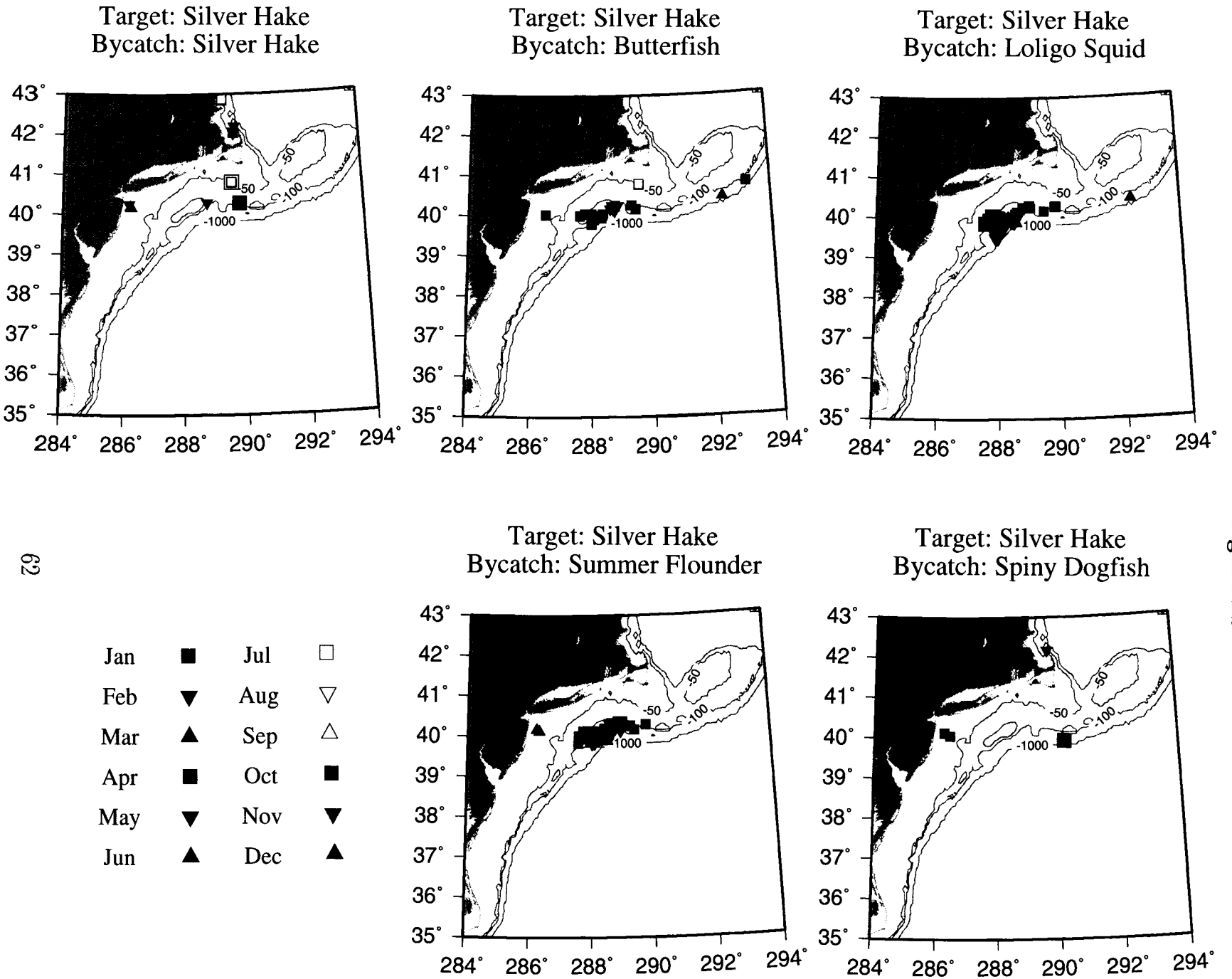


Figure 1b


Target: Silver Hake
Bycatch: Silver Hake
Target: Silver Hake
Bycatch: Butterfish
Target: Silver Hake
Bycatch: Loligo Squid
Target: Silver Hake
Bycatch: Summer Flounder
Target: Silver Hake
Bycatch: Spiny Dogfish
43°
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Dec

Figure 2a

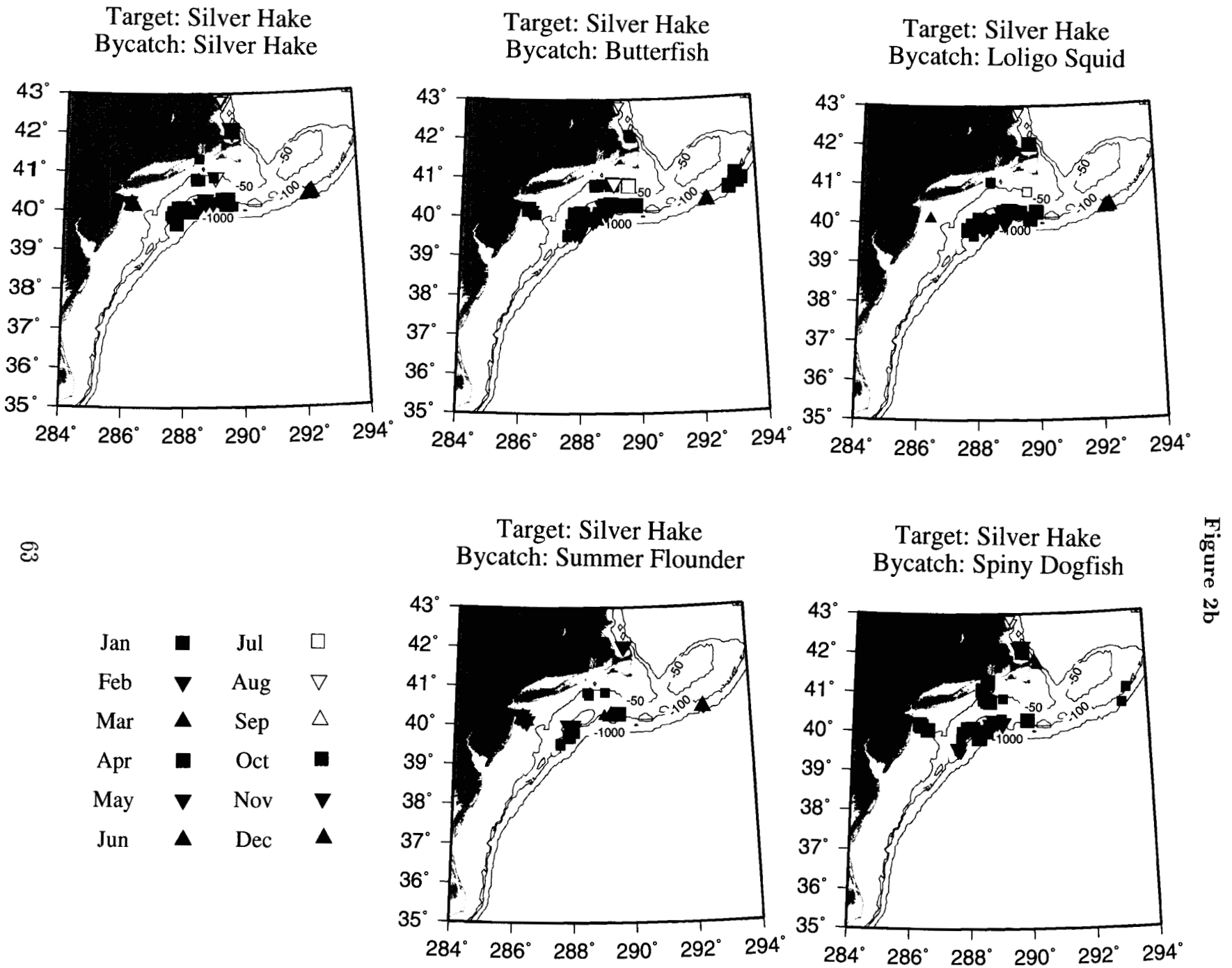
Target: Silver Hake
Bycatch: Silver Hake
Target: Silver Hake
Bycatch: Butterfish
Target: Silver Hake
Bycatch: Loligo Squid
Target: Silver Hake
Bycatch: Summer Flounder
Target: Silver Hake
Bycatch: Spiny Dogfish
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Figure 2b

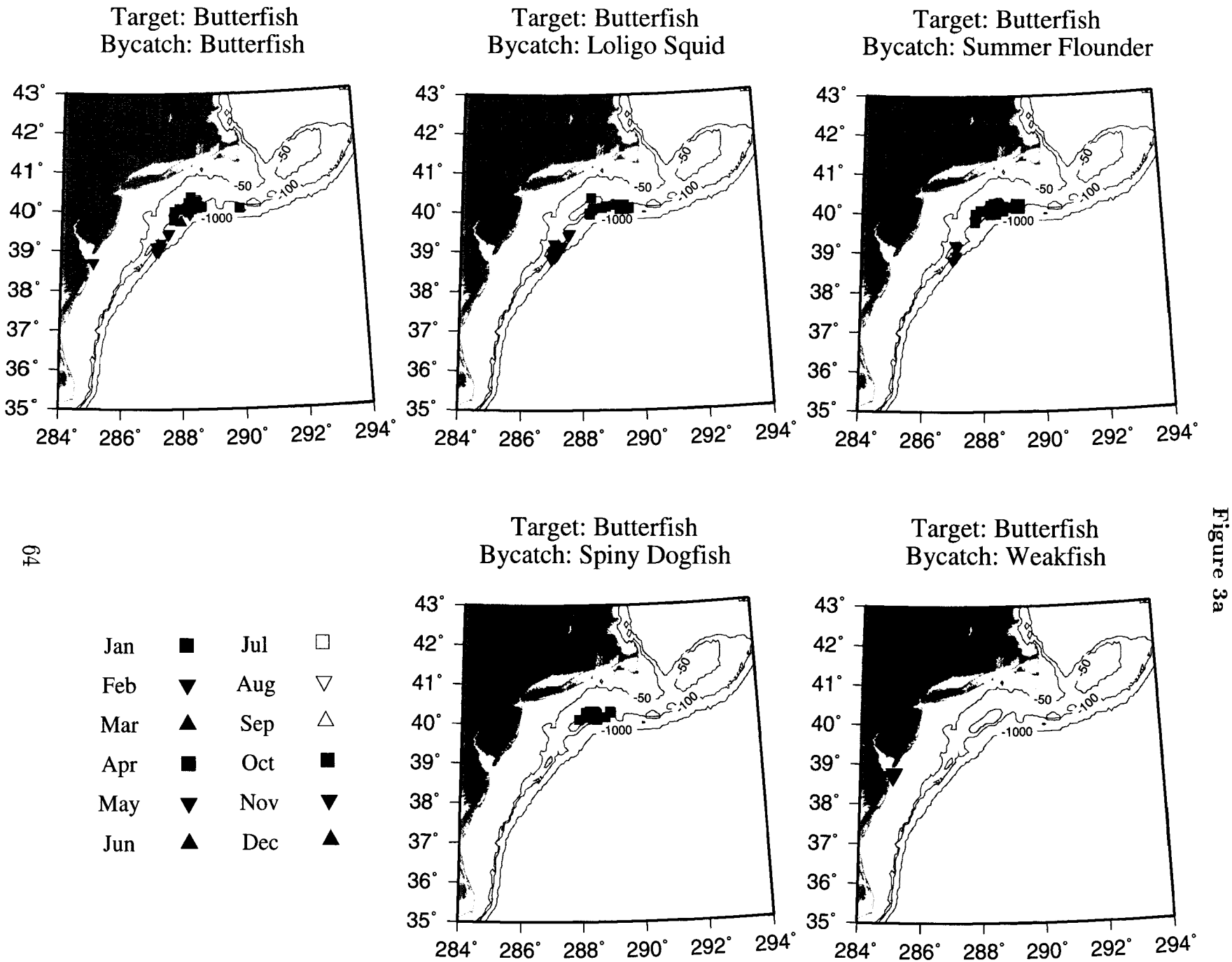
Target: Butterfish
Bycatch: Butterfish
Target: Butterfish
Bycatch: Loligo Squid
Target: Butterfish
Bycatch: Summer Flounder
Target: Butterfish
Bycatch: Spiny Dogfish
Target: Butterfish
Bycatch: Weakfish
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Figure 3a

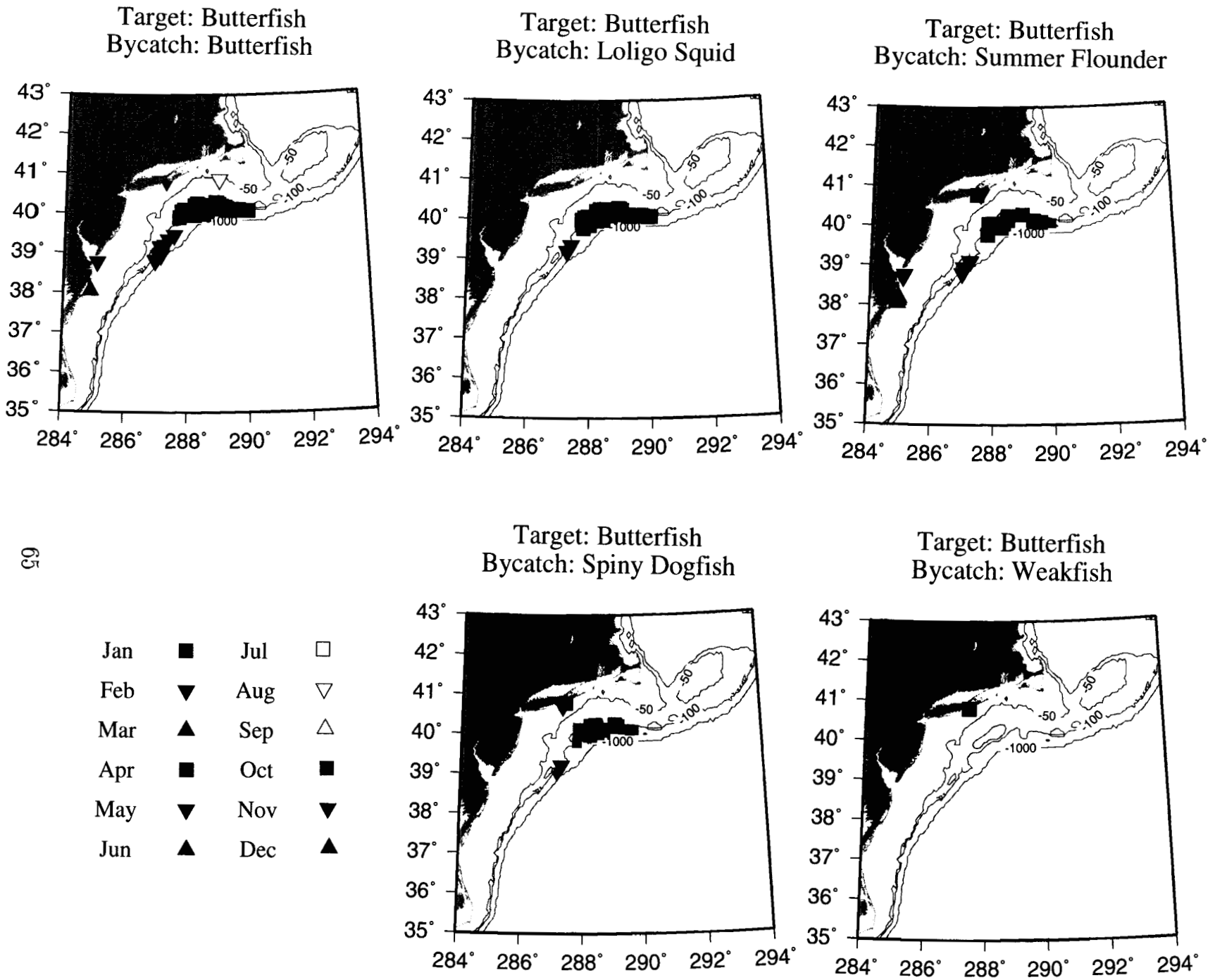
Target: Butterfish
Bycatch: Butterfish
Target: Butterfish
Bycatch: Loligo Squid
Target: Butterfish
Bycatch: Summer Flounder
Target: Butterfish
Bycatch: Spiny Dogfish
Target: Butterfish
Bycatch: Weakfish
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Figure 3b

Figure 4

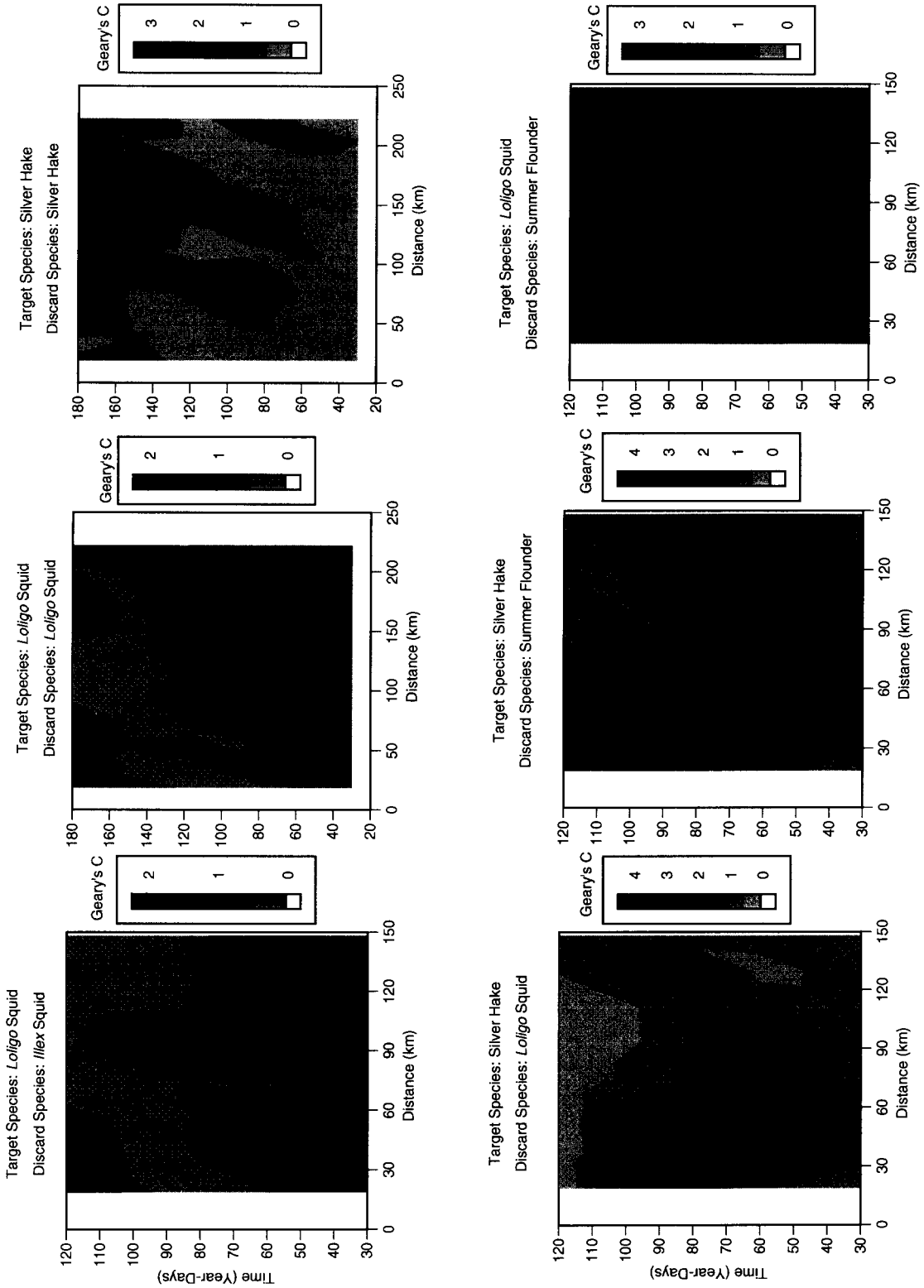
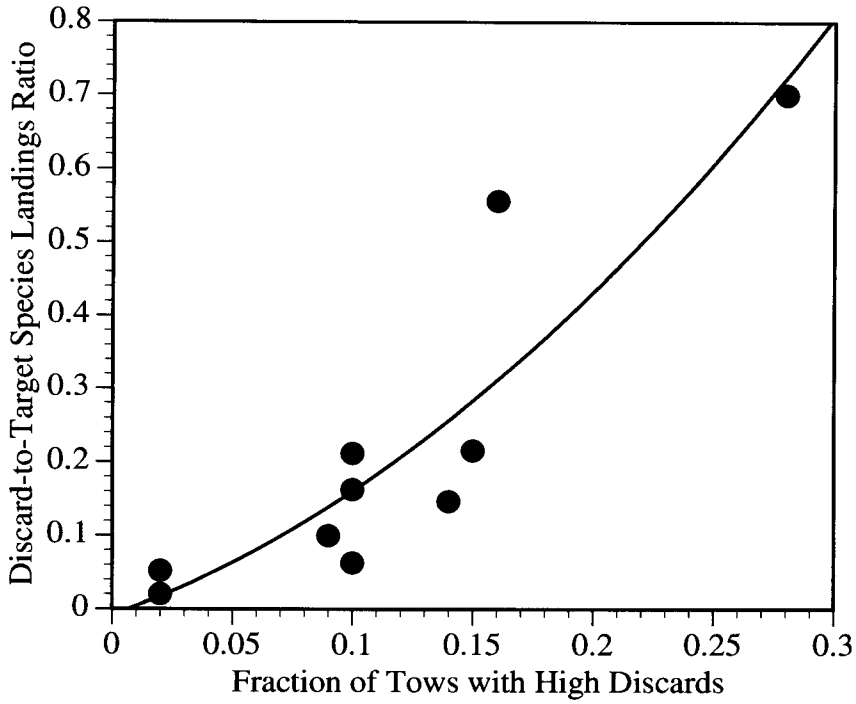

Target Species: Loligo Squid
Discard Species: Illex Squid
Target Species: Loligo Squid
Discard Species: Loligo Squid
Target Species: Silver Hake
Discard Species: Silver Hake
Target Species: Silver Hake
Discard Species: Loligo Squid
Target Species: Silver Hake
Discard Species: Summer Flounder
Target Species: Loligo Squid
Discard Species: Summer Flounder
Geary's C
Time (Year-Days)
Distance (km)

Figure 5


Discard-to-Target Species Landings Ratio
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Fraction of Tows with High Discards

APPROVED
BY Macuda
DATE 10/10/03

Assessment of the Effectiveness of Scup Bycatch-Reduction Regulations in the *Loligo* Squid Fishery

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Allison J. Bonner
Bruce Muller
Eleanor A. Bochenek

Haskin Shellfish Research Laboratory
Rutgers University
6959 Miller Ave.
Port Norris, NJ 08349

Running head: Scup Bycatch-Reduction Regulations

Summary

Discard reduction is a component of the statutory requirements of the Sustainable Fisheries Act. One species of concern is scup, *Stenotomus chrysops*, discarded in the *Loligo pealei* fishery. Initially, regulations were imposed restricting the fishery in time and space to avoid areas and times associated with high scup discarding. Modified gear was required in 2003 on any boat fishing in areas otherwise closed to the fishery to reduce scup discarding. The purpose of this study was to evaluate the success of the 2003 net regulations and the potential influence of time-area closures (GRAs) in achieving a reduction in scup discarding. The regulations are based on three expectations. (1) Reduction in discarding in the *Loligo* squid fishery will materially reduce total scup discarding. (2) Exclusion of *Loligo* squid fishing vessels from the GRAs will result in these vessels fishing in areas that inherently produce fewer scup discards without equivalently increasing discarding in other sensitive species. (3) The use of a square-mesh large-mesh section in the extension will reduce scup discarding to the extent that otherwise would be achieved if the boats fished outside the GRAs without the economic cost imposed by redeploying the fleet.

Analysis of the NMFS-NEFSC observer database offers no support for the belief that Expectation 1 has been met. Squid catches were too low to sustain a directed fishery in the northern GRA during this study. Thus, had this area been open, limited scup discarding would have occurred. In this study, squid catches

averaged 1,025 kg tow^{-1} in the southern GRA. Thus, had the GRA been open, *Loligo* fishing would have taken place. Yet, in the 34 tows taken by two vessels, not a single scup was caught. Redeployment of the fleet clearly increased scup discarding in 2003. Thus, Expectation 2 was not met. Field tests demonstrated that the implemented net modification can produce reduced catches of mostly smaller-sized finfish without impairing squid catch, but the data also indicate that this result may not be routinely achieved. Thus, Expectation 3 was not completely met. Implementation of the 2003 net regulation was likely premature, in that the specification was not adequate to guarantee the desired results. The history of the scup discarding issue in the *Loligo* squid fishery demonstrates that discard reduction cannot be accomplished without adequate prior evaluation of the sources of discards, without the requisite and concomitant experimental evaluation of the results of regulatory reform, and without adequate commercial-scale testing of prospective reforms prior to implementation.

Key words: bycatch, fishery, squid, scup, fisheries management, regulatory reform

Introduction

Discard reduction is a component of the statutory requirements implemented by the "Sustainable Fisheries Act" Amendments to the Magnuson Stevens Fishery Conservation and Management Act. Approaches to managing discards have included gear modifications and area-time closures (e.g., Lök et al., 1997; Murawski, 1996; Karp et al., 2001). The *Loligo* squid fishery of the Mid-Atlantic Bight poses potential difficulties for the management of many commercial species because the legal mesh size used is substantially smaller than that required for other commercial species and the landings and effort in these fisheries is relatively large. Hence, discarding in the small-mesh fisheries could account for a substantial fraction of the yearly total allowable catch of other commercial and recreational species.

One species of concern is scup, *Stenotomus chrysops* (NEFSC, 2000; Kennelly, 1999; Glass et al., 1999). Powell et al. (submitted a) estimated that scup discards in the commercial fisheries were 1.91 times scup landings in 2001, making this species one of the most egregious examples of high discarding among Mid-Atlantic commercial species. Most of the discarded individuals are presumed to die (e.g., NEFSC, 2000). Powell et al. (submitted a) estimated that 2,242,662 kg of scup were discarded in 2001. The fisheries primarily responsible for these discards included *Loligo* squid (6.8%), butterfish (18.7%), silver hake (4.7%), scup (56.0%), and black

sea bass (12.1%) (Powell et al., submitted a,b). Although the vast majority of these discards occur in the scup-directed fishery, the total discarding rate of scup is sufficiently high that discard reduction has been pursued in a number of other fisheries, including the *Loligo* squid fishery.

Beginning in 2000, regulations were imposed restricting the small-mesh fisheries to certain times and locations, often referred to as gear-restricted areas or GRAs, to avoid areas and times associated with high discarding (Anonymous, 2003). High discarding events can contribute significantly to total discards (Stratoudakis et al., 1999). Unfortunately, a direct test of the effectiveness of GRAs has not occurred because no tows have been permitted in these areas to evaluate the probability of high scup discards during GRA times. An alternative approach is the development of gear that would reduce scup capture while retaining squid. Glass (2002) described one possible option that consisted of a large-mesh section in the extension 50 meshes above the codend. Glass (2002) observed a reduction in scup capture, selection favoring the release of smaller scup, and the absence of an effect on squid capture when this modified net was used.

The modified extension recommended by Glass (2002) was inserted into the management framework for the *Loligo* squid fishery in 2003 with a requirement that it be used on any boat fishing in areas otherwise closed to the fishery to reduce scup discarding (Anonymous, 2003). However, the performance of gear in commercial operation may not mirror the performance of gear in experimental mode. Larger catches, for example, may reduce escapement (Godø, 1994). The contribution of individual regulations in achieving management goals is rarely assessed in commercial fisheries; assessment normally relies on changes in stock abundance as a measure of the integrated effect of all regulations. But, regulations that fail to produce results in accordance with expectation increase regulatory complexity, impose unnecessary demands on enforcement, and impose unneeded economic costs on the fishery.

Given the need to reduce scup discarding and the uncertainty of the degree of success of time and area closures in reducing discarding, the efficacy of an alternative approach using modified gear requires evaluation. The purpose of this study was to explicitly evaluate the success of the new 2003 net regulations in the *Loligo* squid fishery in achieving a desired reduction in scup discarding. The specification under test is: "Vessels that are subject to the provisions of the Southern and Northern

Gear Restricted Areas ... may fish ... using trawl nets ... provided that ... the vessel fishes in a GRA only with a specially modified trawl net that has an escapement extension consisting of a minimum of 45 meshes of 5.5 inch (13.97 cm) square mesh that is positioned behind the body of the net and in front of the codend" (Anonymous, 2003). In addition, by conducting the study within the area-time closures, we were able, for the first time, to evaluate the potential influence of GRAs on scup discarding.

Methods

Field Program

The net regulation under test is implemented in two GRAs, one south of Long Island and one east and south of New Jersey (Figure 1). The study was conducted in both GRAs during times when the time-area closure was in effect. Forty tows were observed on two vessels in the northern GRA in November, 2002. Thirty-four tows were observed on two vessels in the southern GRA in January-February, 2003 (Figure 1).

Boats fished the net legal in 2002 (A) and the modified net legal in 2003 (B) in an alternating sequential pattern of paired tows: AB BA AB etc. Nets were typical of the *Loligo* squid industry. The vessels fishing in the northern GRA used 3-bridle 8″ box nets. The vessels fishing in the southern GRA used millionaire nets. Some particulars differed in net design on each boat (Table 1). In the northern GRA, the modified net included a section comprising 45 meshes of 13.97 cm square mesh fully encircling the extension emplaced just above the connection of the codend to the extension. In the field effort in the southern GRA, two boats fished in parallel, using the same sequential pattern, but with the sequential pairs offset to permit four pairwise comparisons of simultaneous tows: A_1A_2, B_1B_2, A_1B_2, and B_1A_2. Because the specification as written did not regulate placement of the square-mesh section in the extension, one boat used the same configuration as used in the northern GRA (B_1), but the other boat used an extension in which the square-mesh section was placed 50 meshes above the connection of the extension with the codend (B_2).

The experimental design of alternating the extension used in a pairwise sequential pattern was incorporated into a standard fishing trip. All tows were run in commercial mode. Captains utilized normal fishing procedures and chose the locations to be fished with two exceptions. Captains were asked to fish within

a GRA and tow times were limited to 2 hr or less to permit an increased number of observed tows per day. Tows of >3 hr are not uncommon in the *Loligo* squid fishery. Tow speeds never varied outside of the range of 3-3.3 knots.

Each tow was brought onboard, all fish sorted to species and weighed. A random selection of up to 100 *Loligo* squid and 100 scup, total catch permitting, were measured on each tow. Total length was measured for scup; mantle length was measured for squid.

Statistical Analysis

Statistical analysis relied on nonparametric ANCOVA to minimize the influence of data non-normality and inhomogeneity of variances (Underwood, 1981; Sokal and Rohlf, 1995). Powell et al. (1984) and Kendall et al. (1985) provide examples comparing this approach to that of log-transformation. Dependent variables included catch weight per tow, the percentiles (25th, 50th, 75th) of the size-frequency distribution, and the mean size. Because one objective was to achieve a proportional decrease in scup catch relative to the catch of *Loligo* squid, the ratio of species catch to *Loligo* squid catch was used as a dependent variable in some analyses. Independent variables included extension configuration (± a 45-mesh section of 13.97 cm square mesh), time-of-day, recognizing that catches of *Loligo* squid and other species are significantly affected by time-of-day (Walsh, 1988; Serchuk and Rathjen, 1974; NEFSC, 2002; Gillis, 1999), and boat. The variable 'boat' was included as a main effect because different net configurations and Captain's preferences in the approach to fishing were expected to exert a significant effect on catch. Effort was used as a covariate in all models. Interaction terms between main effects were routinely included.

Effort could not be calculated directly because the swept area of the tow was not recorded. A surrogate for true effort was obtained as the average of the recorded headrope and footrope lengths multiplied by the recorded tow time and speed. The multiple of tow time and speed is superior to the distance between tow initiation and cessation because tow paths may not be linear (Powell et al., 2003, in press).

In some cases, total catch was also used as a covariate. Total catch used as a covariate permits discrimination of the case where the influence of the net could be explained simply by a reduction in total catch versus the case where a proportional change in the components of the catch occurred.

In cases where boats fished in parallel, the differences between squid or scup catch between simultaneous tows was used, in addition to the catch of these species, as a dependent variable. In this case, the net main effect was replaced by a main effect defining the four possible pairwise net configurations: A_1A_2, B_1B_2, A_1B_2, and B_1A_2. The effort and total catch covariates were replaced by their respective differences.

Chi-square tests were used to evaluate a possible bias introduced by the inhomogeneous distribution of tows with the two extension configurations with time-of-day. *A posteriori* Tukey's Studentized Range tests were used to identify the location of significant differences within the ANCOVAs. A significance level of $\alpha = 0.05$ was used for these tests. The results of these tests should be treated only as a guide in cases where interaction terms were significant.

Results

Descriptive Statistics

Cumulative catch exceeded 100 kg for the 74 tows for 20 species (Table 2). Further analyses of catch weight focused on these twenty species.

The twenty most commonly caught species were not caught in the same proportions in the northern and southern GRA. Catches in the northern GRA consisted primarily of scup, spiny dogfish, little skate, and summer flounder. Relatively little of the target species, *Loligo* squid, was caught. Catches in the southern GRA consisted almost exclusively of *Loligo* squid. No scup were caught.

Time-of-Day Distribution of Tows

Because squid undergo vertical migration, the time of day of the tow is likely to influence the catch. Tows were restricted to daytime hours. Nevertheless, even within this time frame, changes in the catchability of squid occur (e.g., NEFSC, 2002). We allocated tows to three daytime periods: 0600-1100, 1100-0300, and 0300-2000. About one-third of the tows fell within each of these time periods (24, 32, 18, respectively). The net configurations were not towed homogeneously throughout these time periods (Chi-square, $P = 0.049$). Tows with the modified extension occurred somewhat more frequently during the central time period. For this reason, time-of-day was included as a main effect in all subsequent ANCOVA analyses.

Effect of Modified Extension on Catch Weight – General Analysis

Catches of *Loligo* squid varied significantly between boats. The two boats fishing in the fall in the northern GRA caught significantly fewer squid than the two boats fishing in the southern GRA (Tukey's Studentized Range Test, $\alpha = 0.05$). Although the catches of one boat averaged considerably above the other in the southern GRA, an *a posteriori* test did not discriminate between them (Table 3). The modified extension resulted in nearly a factor of three fewer squid being caught per tow. The difference was significant (Table 3). A significant interaction term revealed that one of the boats fishing in the southern GRA was more successful at catching squid with the modified extension than the other three boats. Neither effort nor time-of-day exerted a significant effect.

If total catch was included as a covariate, much of the variation in catch associated with the two different extensions was captured by the covariate. A weakly significant effect remained (Table 3). Nevertheless, the decrease in *Loligo* catch was explained mostly by an overall decrease in total catch with the modified extension. Focusing on the individual boats revealed that the modified extension caught fewer fish in three of the four cases, but confirmed the overall ANCOVA in identifying one of the vessels fishing in the southern GRA as being unusual. Average squid catch per tow for this boat was about the same regardless of the extension used.

Scup were caught only in the northern GRA. Considerably fewer scup were caught using the modified extension (Table 4). If total catch was included as a covariate, the influence of the extension was captured by the covariate, indicating that much of the loss of scup was explained by an overall decrease in catch.

Besides *Loligo* squid, nine species were caught frequently in both GRAs. The catches differed significantly between boats fishing in the northern GRA and the southern GRA in all but one case (Table 5). In a number of cases, monkfish, butterfish, silver hake, smooth dogfish, and summer flounder, the catches differed significantly between the two boats fishing in the southern GRA. Time-of-day never exerted a significant main effect. Interaction terms were significant only for silver hake and smooth dogfish. Effort and total catch were occasionally significant covariates (Table 5). Thus, inherent differences in catch rate between boats was among the most important sources of variation explaining the observed differences in catch.

Among these nine species, the normal and modified extensions produced significantly different catches only for butterfish and silver hake. In both cases, catches were lower with the modified extension (Table 5). Unlike *Loligo* squid and scup, in neither case was this difference explained by variations in total catch.

A number of fish were caught predominately in one or the other GRA, but not both. Among these species, time-of-day exerted a significant main effect only for John dory. Interaction terms were never significant. Effort was rarely significant; however, total catch was significant as a covariate for most species (Table 6). The normal and modified extensions produced significantly different catches only for bluefish. Catch was lower with the modified extension; however, this difference was explained by variations in total catch (Table 6).

Effect of Modified Extension on Catch Weight – Paired Tows

In the case of the southern GRA, two vessels towed in parallel, thus permitting direct comparisons among boats and extension configurations. Analysis of paired tows supported the conclusions that boats fishing with the modified extension caught significantly fewer *Loligo* squid ($P < 0.0001$) and that this effect was absorbed by the total catch covariate when it was included in the analysis. This analysis also confirmed that the modified extension caught significantly fewer silver hake ($P = 0.022$) and that this effect was not explained by variations in total catch ($P = 0.0016$ with total catch included as a covariate). The analysis also identified a marginally significant effect for *Illex* squid ($P = 0.049$), but this result might have occurred by chance (binomial test, $\alpha = 0.05$), whereas chance was an unlikely explanation for the other significant results.

Effect of Modified Extension on Catch Weight – Ratio to *Loligo* Catch

The goal of the modified gear was to reduce catch of finfish, particularly scup, while not affecting the catch of *Loligo* or while reducing *Loligo* catch only to a limited extent. Accordingly, we evaluated the ratio of catches of various species to that of *Loligo* squid, expecting this ratio to decline with the modified gear. Although scup catch declined significantly, the ratio of scup to *Loligo* did not vary significantly with extension configuration, indicating that both *Loligo* squid and scup decreased in approximate proportion in catches of boats fishing with the modified extension in the northern GRA. Scup were not caught in the southern GRA.

Two species did elicit a significant effect between the ratio of species catch-to-

Loligo catch and the extension configuration used: silver hake ($P = 0.0002$; with total catch as a covariate, $P = 0.011$), butterfish (with total catch as a covariate, $P = 0.0063$). In both cases, the ratio was higher with the unmodified extension, indicating that the drop in catch of butterfish and silver hake in tows using the modified extension was proportionately larger than the change in *Loligo* squid catch. The effect occurred both in the northern GRA [significant for butterfish ($P = 0.0003$)] and the southern GRA [significant for silver hake ($P = 0.0009$)].

In the case of the one boat in which the catch of *Loligo* squid was unaffected by the modified extension, the ratio of silver hake-to-*Loligo* squid was significantly lower when the modified extension was used [silver-hake-to-*Loligo* squid ratio: 0.00356 versus 0.00173 ($P = 0.02$)]. Thus, silver hake escapement was increased in this case while *Loligo* squid retention was unchanged.

Size-Frequency Shifts

The modified extension was expected to increase escapement of smaller finfish while retaining *Loligo* squid. Therefore, shifts in the size-frequency distribution emphasizing the larger size classes were anticipated in tows using the modified extension for fish such as scup, whereas no such change was anticipated in the size-frequency of *Loligo* squid retained.

Sufficient data were available to evaluate the size-frequencies of black sea bass, silver hake, summer flounder, scup, and *Loligo* squid catches, at least on some boats. No significant changes in the size frequency of black sea bass, silver hake, or summer flounder were observed. The seventy-fifth percentile of size was significantly higher in scup retained in nets using the modified extension ($P = 0.031$). Thus, a tendency existed for smaller scup to escape from this net relative to the net with the unmodified extension.

The case for *Loligo* squid was more complex. The twenty-fifth percentile, the median, and the mean size were significantly higher in tows using the modified extension ($P = 0.021, P = 0.049, P = 0.031$, respectively). A significant boat effect was present in all three cases ($P < 0.0001$). For the mean, the interaction term between boat and extension was also significant ($P = 0.041$). The boat fishing in the southern GRA that was characterized by equivalent squid catches regardless of the extension design used caught significantly larger squid than the other boats. For this vessel, the size frequency of squid caught also did not materially change between the two extension designs. In contrast, in the other cases, in which the

boats caught significantly fewer squid when the modified extension was used, the squid retained averaged a significantly larger size (Table 7).

Discussion

Perspective

Regulatory reduction of scup discards in the *Loligo* squid fishery has focused on area-time closures otherwise known as gear-restricted areas or GRAs. This approach has significantly impaired prosecution of the *Loligo* squid fishery with concomitant economic and sociological impacts. As a consequence, efforts have been directed at mechanisms to permit exclusion of boats from the GRA closure based upon the utilization of net designs that would reduce scup discarding. One such modified net was permitted to be operated inside the GRAs in 2003. This net has a large-mesh (13.97 cm square mesh) section of 45 meshes in the extension above the codend.

The success of these regulations in achieving a desired reduction in scup discarding is dependent upon three expectations. (1) Reduction in discarding in the *Loligo* squid fishery will materially reduce total scup discarding. (2) Exclusion of *Loligo* squid fishing vessels from the GRAs will result in these vessels fishing in areas that inherently produce fewer scup discards without equivalently increasing discarding in other sensitive species. (3) The use of a square-mesh large-mesh section in the extension will reduce scup discarding to the extent that would be otherwise achieved if the boats fished outside the GRAs without the economic cost imposed by redeploying the fleet. Have these three expectations been met?

Expectation 1: Reduction in discarding in the *Loligo* squid fishery will materially reduce total scup discarding.

Powell et al. (submitted a) analyzed the NMFS-NEFSC[†] observer database for 1997-early 2002. They estimated that scup discards for 2001 totaled 2,242,662 kg. The fisheries primarily responsible for these discards included *Loligo* squid (6.8%), butterfish (18.7%), silver hake (4.7%), scup (56.0%), and black sea bass (12.1%). Of these, the directed scup fishery accounted for more than half of total scup discards. Scup, black sea bass, and butterfish accounted for 86.8% of total scup discards.

Scup was not a significant bycatch species in the *Loligo* squid fishery. Scup catch was 0.65% of total catch in observed *Loligo*-targeted tows (Powell et al., submitted

[†] National Marine Fisheries Service-Northeast Fisheries Science Center

a). Focusing on perhaps the more important ratio, scup discards-to-target species landings, the ratio averaged 0.0135 in *Loligo*-targeted tows. High scup-discarding events occurred rarely. Cases of scup catch exceeding 100 kg tow^{-1} occurred in only 19 of 1,597 observed tows (Powell et al., submitted a). Scup were discarded in only 23% of *Loligo*-targeted tows. The inference is that these two species rarely overlap significantly in geographic space (see also Cadrin et al., 1995).

Regardless of the fishery, the overwhelming reason given for the discarding of scup was the legal landing size, presently set at 22.9 cm. Discarded scup were below legal landing size. In the *Loligo* squid fishery, a non-trivial quantity of scup was discarded due to closure of the scup season, but overall, at least 90% of all scup discards in the Mid-Atlantic Bight originated from the landing size regulation (Powell et al., submitted a).

The analyses presented by Powell et al. (submitted a) suggest that regulations limiting scup discarding in the *Loligo* squid fishery are unlikely to substantially impact scup discarding as a whole. In addition, the same analyses indicate that a simple change in the landing size would accomplish more than a host of other approaches aimed at gear modifications and area-time closures. Not surprisingly, Powell et al. (submitted a) could not find a significant decrease in scup discarding post-2000 in comparison to earlier years, based on NMFS-NEFSC-observed tows. However, the total amount of scup discards in the *Loligo* squid fishery is so small that halving them would be difficult to discern statistically in the observer database. Nevertheless, analysis of the NMFS-NEFSC database offers no support to the belief that Expectation 1 has been met.

Expectation 2: Exclusion of *Loligo* squid fishing vessels from the GRAs will result in these vessels fishing in areas that inherently produce fewer scup discards without equivalently increasing discarding in other sensitive species.

One of the critical issues in the application of GRAs to reduce discarding is the inability to objectively evaluate success because exclusion of the fishery from the GRA prevents collection of data to appraise the degree to which discarding was reduced. Thus, since implementation of the GRAs, no information has been obtained to permit estimation of what the discarding rate might have been inside the GRAs for comparison to the observed rate of discarding outside the GRAs

obtained from the NMFS-NEFSC database. The present study represents the first tows taken within the GRAs since their imposition. Evaluating Expectation 2, then, is problematical. The following observations can be made, however.

Powell et al. (submitted a) did not observe a reduction in scup discarding in *Loligo*-targeted tows since the GRAs were imposed. Some other commonly discarded species in *Loligo*-targeted tows had increased rates of discarding, including butterfish, summer flounder, and spiny dogfish. Whether this increased discarding is a product of fleet redeployment during GRA times is unclear. Increased stock abundances might also be responsible; however, the data do not exclude this possibility that fleet redeployment is responsible.

In this study, the catches of scup and *Loligo* squid support the suspicion that the imposition of GRAs has, at the very least, had no effect on scup discarding and may have increased scup discarding. Scup was the primary fish caught in the northern GRA during the November study. *Loligo* squid catches were consistently low throughout the study and tows covered a substantial fraction of the GRA (Figure 1). Average catch per tow was 248.7 kg of scup and 57.3 kg of *Loligo* squid. Squid catches were too low to sustain a directed fishery in this GRA in November; in fact, high discarding events are not recorded in this area during the three years prior to GRA implementation during the times that the GRAs are now in force (Figure 2). Thus, had this area been open, limited fishing would have occurred and, therefore, limited scup discarding would have occurred. In accordance with this observation, based on NMFS-NEFSC observer data, *Loligo*-targeted tows occurred rarely in this GRA during the effective time period prior to imposition of the GRAs (Figure 3).

A very different situation existed in January-February in the southern GRA. Very few high discard occurrences are recorded in the NMFS-NEFSC database in the northern GRA and none during the time period that the GRA is in force. High discarding events are recorded in the southern GRA during that time period and in the same general area as fished in this study (compare Figures 1 and 2). The number of such discarding events is few, however. In this study, squid catches averaged 1,025 kg tow^{-1} in the southern GRA. Thus, had the GRA been open, *Loligo* fishing almost certainly would have taken place and been relatively intensive. Yet, in the 34 tows taken by two vessels, not a single individual scup was caught. Thus, had this area been open to fishing, fishing certainly would have occurred and scup discarding

would have been low.

Although information is not available, the inference from these observations is that redeployment of the fleet did not occur in November because little fishing would have taken place in the GRA at that time, and, as a consequence, the northern GRA did not reduce scup discarding in 2002. In comparison, redeployment of the fleet certainly occurred in January-February farther south and this redeployment clearly increased scup discarding because the southern GRA encompassed a significant area where *Loligo* squid fishing could have taken place without significant discarding in 2003. The evidence, problematic thought it may be, appears to indicate that Expectation 2 has not been met.

Expectation 3: The use of a square-mesh large-mesh section in the extension will reduce scup discarding to the extent that would be otherwise achieved if the boats fished outside the GRAs without the economic cost imposed by redeploying the fleet.

Even if discarding rate is low, a reduction in discarding is efficacious. Thus, the design of a modified net reducing scup catch in the *Loligo* squid fishery is a useful endeavor. We tested the regulated modification against the net used outside the GRAs on four boats and in both GRAs. For the net modification to be successful, *Loligo* squid catch should not be substantially impaired, whereas scup catch should be reduced. On three of the four vessels, *Loligo* squid catch was significantly reduced. Scup catch was also reduced on the two vessels fishing in the northern GRA where scup were caught, but this reduction in scup catch could be explained by the reduction in total catch observed with the modified net. That is, selection against scup did not occur. For the other species that showed significant changes in catch, the same explanation existed with two exceptions, butterfish and silver hake. A proportional increase in escapement occurred for both of these fish.

The second boat fishing in the southern GRA was interesting in that *Loligo* squid catches did not decline when the modified extension was used. This observation agrees with the observations of Glass (2002) of the same net configuration. Unfortunately, this boat fished in the southern GRA where scup were not present, so the impact on scup could not be tested. However, a few observations are pertinent. Butterfish and silver hake catches were observed to be proportionately reduced in tows using the modified extension. For silver hake, this reduction occurred as well

with the boat in which the *Loligo* squid catches were not affected. Thus, the data suggest that the insertion of a 13.97 cm square-mesh section in the extension can reduce the capture of highly mobile finfish like silver hake, butterfish and scup. Unfortunately, the data also indicate that this is likely not to be routinely achieved in the fishery because of large boat-to-boat variations in net performance.

Size-frequency shifts were observed in two cases, *Loligo* squid and scup. The shift in scup suggests that the catchability of smaller scup was reduced relative to larger scup using the modified extension. This result conforms with the observations of Glass (2002). Because juvenile scup weigh less, preferential exclusion of juveniles might not impact total catch weight significantly. We did not see a proportional decrease in scup catch when compared to total catch or *Loligo* squid catch in accordance with this inference.

Small *Loligo* squid were preferentially lost by the boats that showed a reduction in *Loligo* squid catch when using the modified extension. The one boat that also did not see a change in *Loligo* squid catch did not see a change in squid size frequency. This latter dataset also conforms to the observations of Glass (2002).

Overall, the data indicate that the modified extension can produce reduced catches of mostly smaller-sized finfish without impairing squid catch, as documented by Glass (2002), but the data also indicate that this result may not be routinely achieved. The large boat-to-boat variation in net performance is the critical observation. The modified extension was relatively successful on one boat and not so on the other three. The difference did not accrue from a change in the position of the large-mesh section, nor was it associated with depth or vessel speed, although depth and vessel speed are known to significantly affect trawl performance (Koeller, 1991; Somerton and Weinberg, 2001; Godø and Engås, 1989). The specifications were ambiguous concerning the position of the large-mesh section in the extension; hence we tested two different configurations, but vessels with both configurations saw equivalent decreases in catch. Regardless of the reason, clearly, implementation of the modified extension based on the published specification (Anonymous, 2003) did not produce dependable results. In cases where *Loligo* squid catch was reduced, that variations in scup (and other species) catches could be explained by variations in total catch in most cases, indicates that a decision by the Captain to increase effort to obtain the desired *Loligo* catch would likely negate any positive effect of the modified extension on scup discarding.

Thus, Expectation 3 was not completely met. What seems clear is that implementation of this regulation was likely premature, in that the specification was not adequate to guarantee the desired results on all vessels. More experimentation is desirable to provide a net description for regulation that would be more likely to consistently achieve the desired results.

Conclusions

Much time and effort have been expended to reduce scup discarding in the *Loligo* fishery, without favorable results. What lessons can be learned?

The original premise would appear to be invalid. Scup discarding is primarily contributed by other fisheries besides *Loligo* squid. And, the simplest regulatory reform, reducing the minimum size limit, has not been employed even though that regulatory change would achieve dependable and easily predictable results.

As a consequence, successful regulatory reform to reduce scup discarding was predestined for failure. Imposed regulations were much more likely to increase discarding than reduce it. Moreover, regulations implemented could not be evaluated for success, preventing rapid reassessment of failed regulatory decisions. Imposition of GRAs without establishing a mechanism to evaluate the relative impact on discarding by fleet redeployment, as occurred in this case, makes evaluation of the degree of success nearly impossible and consequently prevents inculcation of confidence in the regulatory approach. In the case of the GRAs for the *Loligo* squid fishery, the data suggest, but can never prove, that discarding has, if anything, been increased.

Finally, in the desire to minimize the economic damage to the fishery produced by the GRAs, gear regulations were imposed without adequate test in commercial mode. Low gear performance and the apparent mismatch between GRA boundaries and scup discarding is likely to instill mistrust in science and management that emplaces barriers to future success while minimizing future industry cooperation (e.g., Policansky, 1998; McCay, 1988), particularly when the gain in stock sustainability cannot be shown to match the apparent economic cost. As a consequence, the present regulatory morass can accomplish little positive effect in reducing scup discarding. The history of the scup discarding issue in the *Loligo* squid fishery demonstrates that discard reduction cannot be accomplished without adequate prior evaluation of the sources of discards, without the requisite and

concomitant experimental evaluation of the results of regulatory reform, and without adequate commercial-scale testing of prospective reforms prior to, as well as following, implementation.

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Figure Legends

Figure 1. Map of the Mid-Atlantic Bight showing the locations of the northern and southern GRAs and the locations of the tows taken in these two GRAs during this study.

Figure 2. The location of tows characterized by a high level of scup discarding with respect to the northern and southern GRA. The larger symbol represents tows with scup discarding in the range >1,000 kg tow^{-1}; the smaller symbol, tows in the range >100-1,000 kg tow^{-1}. Data taken from Powell et al. (submitted a).

Figure 3. The location of *Loligo*-targeted tows in which fish of any species were discarded with respect to the northern GRA. Symbol sizes represent total discards (all species combined) in units of kg tow^{-1}. Data taken from Powell et al. (submitted a).

Figure 1

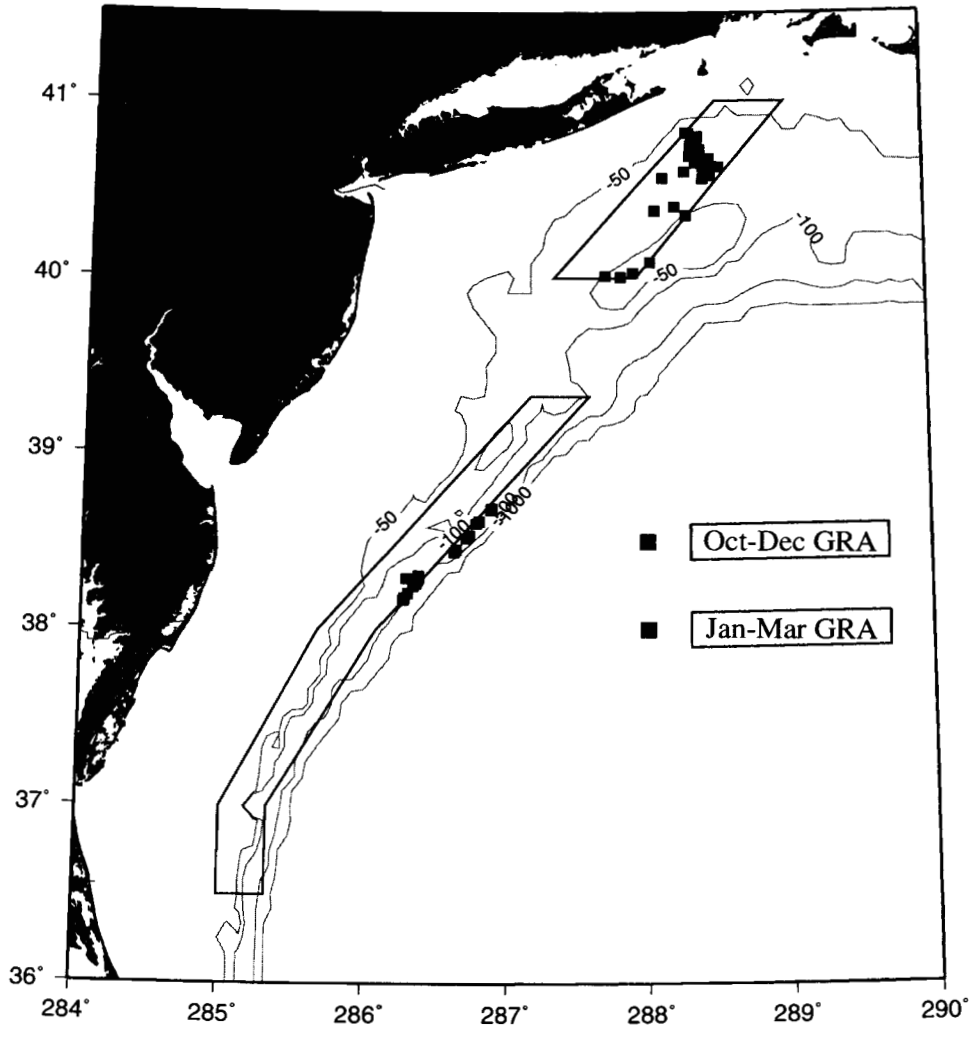
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Figure 2

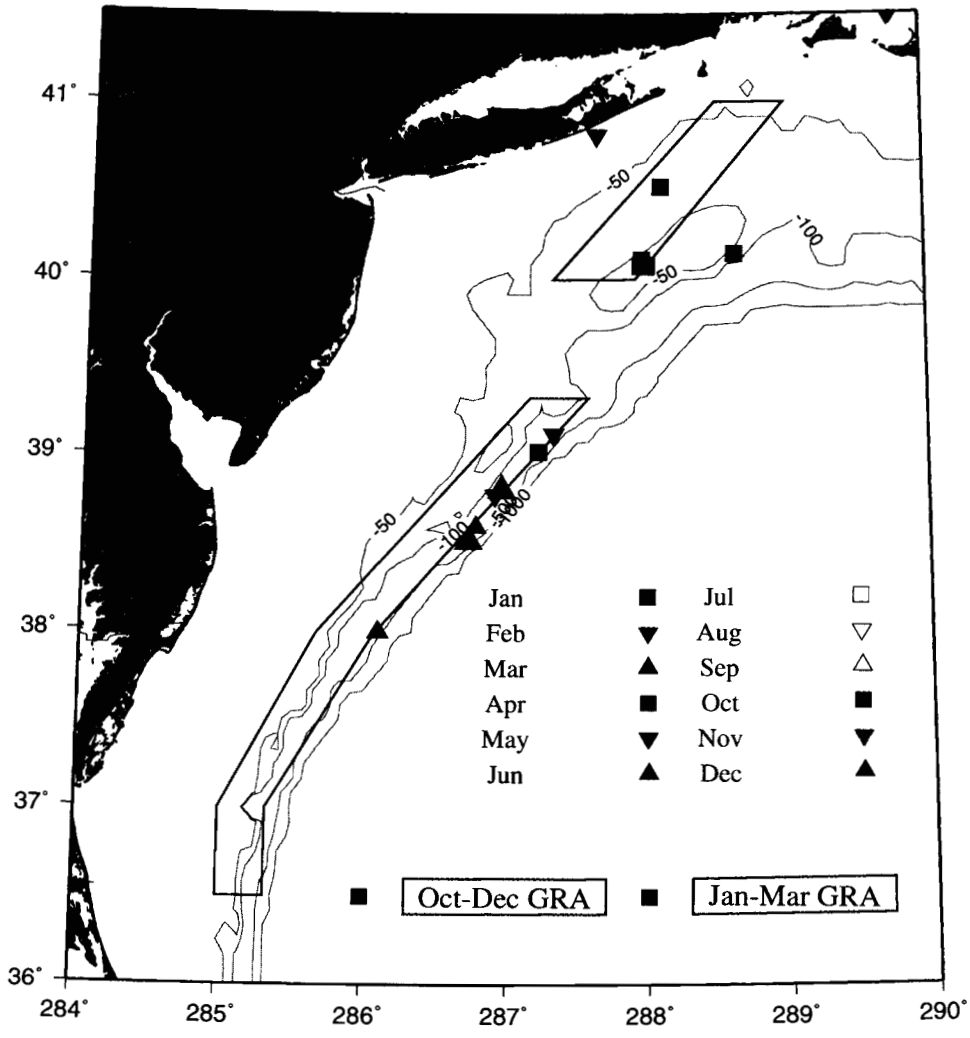
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Figure 3

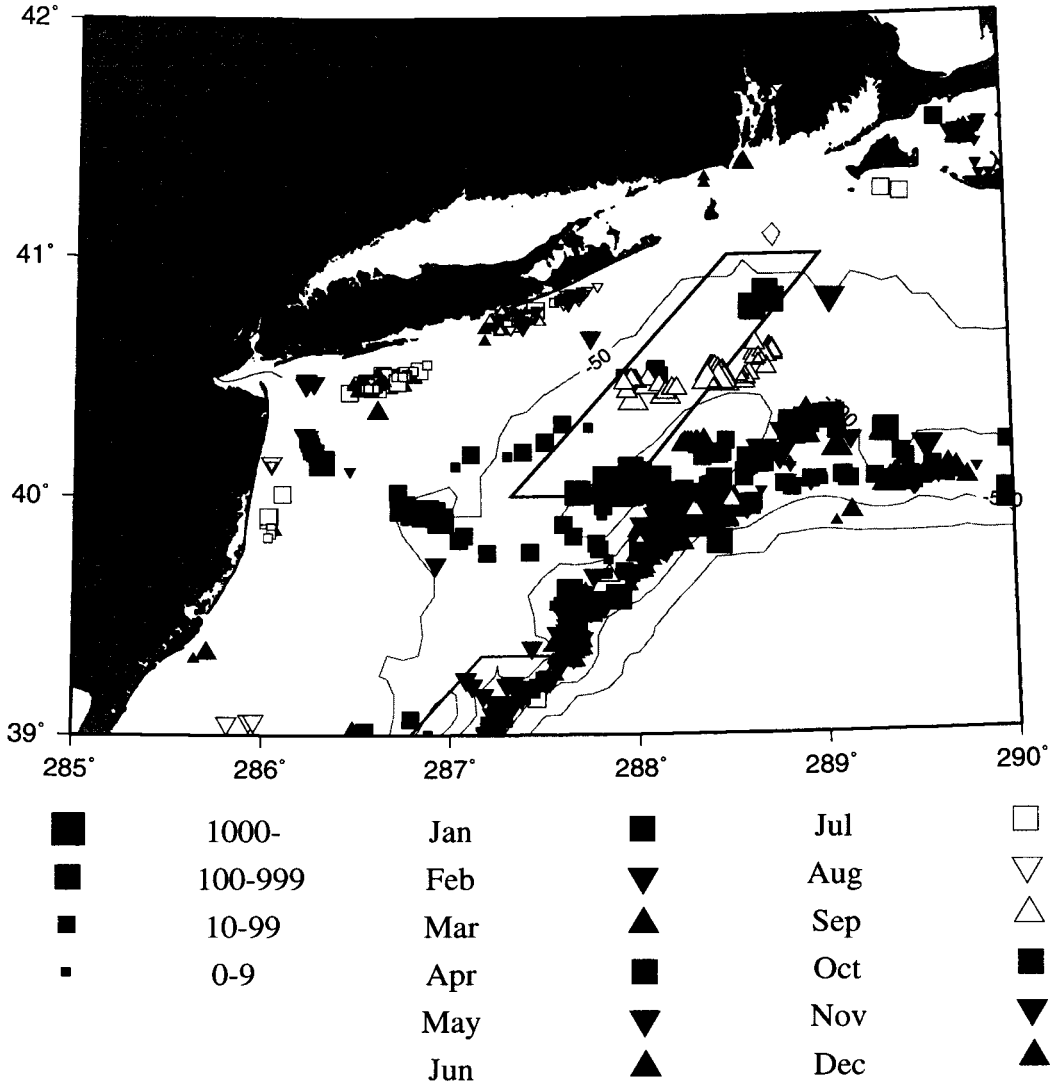
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Table Legends

Table 1. Descriptive data for the nets used on each boat.

Table 2. Cumulative catch (in kg) for the 74 tows taken during this study.

Table 3. Results of ranked ANCOVA on catch of *Loligo* squid. Boats 1 and 2 fished in the northern GRA. Boats 3 and 4 fished in parallel in the southern GRA.

Table 4. Results of ranked ANCOVA on catch of scup in the northern GRA.

Table 5. Results of ranked ANCOVA on catch of selected species. Boats 1 and 2 fished in the northern GRA. Boats 3 and 4 fished in parallel in the southern GRA.

Table 6. Results of ranked ANCOVA on catch of selected species. Boats 1 and 2 fished in the northern GRA. Boats 3 and 4 fished in parallel in the southern GRA.

Table 7. Percentiles of the size-frequency distribution and the mean of the size frequency distribution (in cm) for *Loligo* squid and scup. Boats 1 and 2 fished in the northern GRA. Boats 3 and 4 fished in parallel in the southern GRA.

Table 1

Vessel	Net Style	Headrope	Footrope	Ground Cable	Fishing Circle	Codend
Boat 1	3-bridle 8″ box net	28.26 m	27.43 m (wrapped cable)	155.45 m (rubber cookies)	327 meshes 15.24 mesh	double twine diamond hung 4.76 cm mesh with strengthener chaffing gear
Boat 2	3-bridle 8″ box net	24.38 m	29.26 m (rubber cookies)	146.30 m (rubber cookies)	356 meshes 16 cm mesh	double twine diamond hung 4.76 cm mesh with strengthener chaffing gear
Boat 3	Millionare	53.34 m	53.34 m (rubber cookies)	82.30 m (cable/wire)	4.57 m mesh	double twine diamond hung 6 cm mesh with strengthener chaffing gear
Boat 4	Millionare	42.67 m	42.67 m (rubber cookies 90.72 kg lead)	91.44 m	40 meshes 4.57 m mesh 4.76 cm mesh	double twine diamond hung with strengthener

Table 2

Species Caught		Cumulative Catch (kg)	Northern GRA Catch (kg)	Southern GRA Catch (kg)
Loligo Squid	*Loligo pealei*	37,133.3	2,293.2	34,840.2
Scup	*Stenotomus chrysops*	9,949.9	9.949.9	0.0
Spiny Dogfish	*Squalus acanthias*	7,642.2	6,784.3	858.0
Little Skate	*Leucoraja eriancea*	4,970.3	4,970.3	0.0
Summer Flounder	*Paralichthys dentatus*	3,444.8	3,111.0	333.8
Butterfish	*Peprilus triacanthus*	2,282.5	2,259.2	23.3
Monkfish	*Lophius americanus*	1,301.7	999.5	303.1
Bluefish	*Pomatomus saltatrix*	919.6	918.9	0.7
Illex Squid	*Illex illecebrosus*	701.4	0.0	701.4
Black Sea Bass	*Centropristis striata*	648.5	516.9	131.6
Fourspot Flounder	*Paralichthys oblongus*	398.6	386.5	12.1
Smooth Dogfish	*Mustelus canis*	336.9	206.7	130.1
Gulfstream Flounder	*Citharichthys arctifrons*	323.9	323.9	0.0
Silver Hake	*Merluccius bilinearis*	222.9	189.4	33.5
Atlantic Mackerel	*Scomber scombrus*	195.8	0.0	195.8
Spotted Hake	*Urophycis regia*	144.0	1.8	142.2
Winter Flounder	*Pleuronectes americanus*	134.7	134.7	0.0
Red Hake	*Urophycis chuss*	130.5	130.5	0.0
Witch Flounder	*Glyptocephalus cynoglossus*	130.1	112.8	17.3
John Dory	*Zenopsis conchifera*	106.3	0.1	106.2

Table 3

	Loligo Squid			
Variable	All Boats	Boats 1 and 2	Boat 3	Boat 4
Boat	$P < 0.0001$	NA	NA	NA
Extension	$P = 0.0004$	$P = 0.029$	$P = 0.02$	–
Boat*Extension	$P = 0.023$	NA	NA	NA
Time-of-Day[1]	–	–	–	–
Effort	–	–	–	–
Boat	$P < 0.0001$	NA	NA	NA
Extension	$P = 0.023$	–	–	–
Boat*Extension	–	NA	NA	NA
Time-of-Day[1]	–	–	–	–
Effort	–	–	–	–
Total Catch	$P < 0.0001$	$P = 0.016$	$P = 0.022$	$P = 0.0003$
Catch per Tow[2]				
Normal Extension		88.26±60.56	1,942.12±752.84	870.14±431.11
Modified Extension		33.84±25.22	373.48±260.40	817.75±357.05

[1]Significant interaction terms with time-of-day and boat or net did not occur more frequently than expected by chance. [2]Mean±standard deviation. –, not significant at $\alpha = 0.05$. NA, not applicable.

Table 4

Variable	Scup Catch
Extension	$P = 0.0078$
Time-of-Day[1]	–
Effort	–
Extension	–
Time-of-Day[1]	–
Effort	–
Total Catch	$P < 0.0001$
Catch per Tow[1]	
Normal Extension	428.30±712.96
Modified Extension	75.53±255.30

[1]Mean±standard deviation. –, not significant at $\alpha = 0.05$.

Table 5

Variable	Witch Flounder	Monkfish	Black Sea Bass	Fourspot Flounder	Silver Hake	Butterfish	Smooth Dogfish	Spiny Dogfish	Summer Flounder
Boat	$P = 0.026$	$P < 0.0001$	–	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P = 0.0004$	$P = 0.045$	$P < 0.0001$
Extension	–	–	–	–	$P < 0.0001$	$P < 0.0001$	–	–	–
Boat*Extension	–	–	–	–	–	$P = 0.024$	–	–	–
Time-of-Day[1]	–	–	–	–	–	–	–	–	–
Effort	–	$P = 0.005$	–	–	–	–	–	–	$P < 0.0001$
Boat	$P = 0.028$	$P < 0.0001$	–	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P = 0.0005$	$P = 0.0017$	$P < 0.0001$
Extension	–	–	–	–	$P < 0.0001$	$P = 0.0003$	–	–	–
Boat*Extension	–	–	–	–	$P = 0.0074$	$P = 0.016$	–	$P = 0.041$	–
Time-of-Day[1]	–	–	–	–	–	–	–	–	–
Effort	–	$P = 0.0064$	–	–	–	–	–	–	$P < 0.0001$
Total Catch	–	$P = 0.05$	–	–	$P = 0.0001$	–	–	$P < 0.0001$	$P = 0.015$
Catch per Tow[2]									
Boats 1 and 2									
Normal Extension	3.49±5.38	30.66±42.83	17.78±43.94	14.32±15.03	8.75±8.44	115.36±72.03	4.24±4.86	291.51±493.15	84.73±59.52
Modified Extension	1.88±3.64	20.76±15.29	6.52±12.37	5.46± 4.00	1.64±1.63	15.81±11.03	1.39±1.96	88.78± 98.81	76.73±42.07
Boat 3									
Normal Extension	0.05±0.11	1.78± 3.51	8.18±21.51	0.02± 0.03	0.28±0.29	0.47± 0.63	0.81±0.95	9.83± 10.70	3.13± 3.38
Modified Extension	0.00±0.00	3.71± 4.50	1.20± 2.34	0.56± 1.18	0.03±0.05	0.13± 0.11	0.20±0.45	14.17± 27.17	3.79± 4.06
Boat 4									
Normal Extension	1.18±1.45	17.55±10.74	4.76±11.69	0.51± 0.63	2.56±2.19	1.24± 0.92	6.03±6.36	47.64±104.94	13.24±13.43
Modified Extension	0.79±0.70	12.44±10.01	0.70± 1.25	0.37± 0.33	1.00±0.86	0.86± 1.08	8.37±6.84	28.42± 27.29	19.53±13.97

[1]Significant interaction terms with time-of-day and boat or net occurred more frequently than expected by chance. Time-of-day*net interaction terms were signifiant for silver hake and smooth dogfish. [2]Mean±standard deviation. –, not significant at $\alpha = 0.05$.

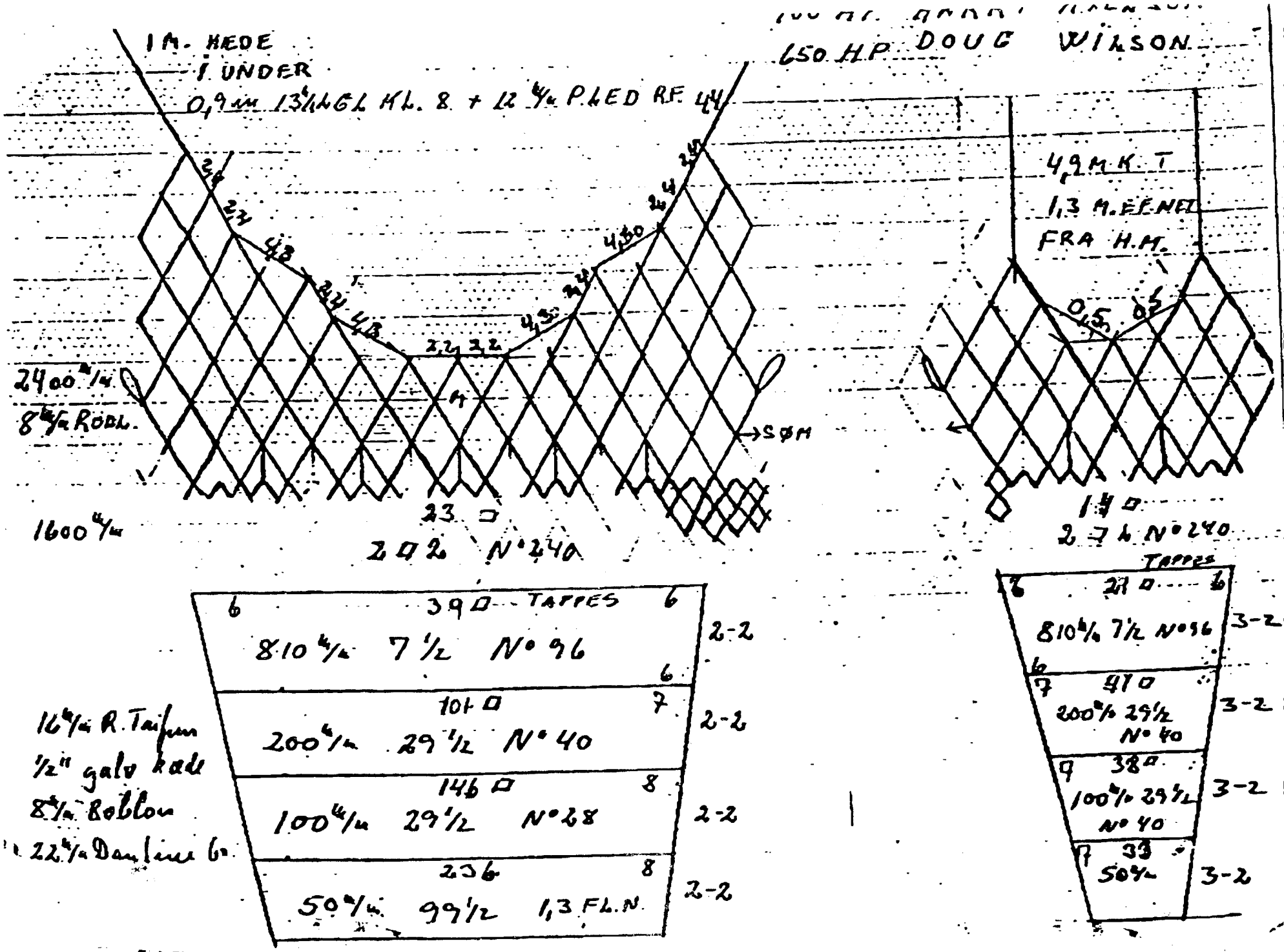
Table 6

Variable	Bluefish	Gulfstream Flounder	Skate	Red Hake	Winter Flounder	*Illex* Squid	John Dory	Atlantic Mackerel	Spotted Hake
Extension	$P = 0.0054$	–	–	–	–	–	–	–	–
Time-of-Day[1]	–	–	–	–	–	–	$P = 0.012$	–	–
Effort	–	–	–	–	–	–	–	–	–
Extension	–	–	–	–	–	–	$P = 0.038$	–	$P = 0.016$
Time-of-Day[1]	–	–	–	–	–	–	$P = 0.0016$	–	–
Effort	–	–	–	–	–	–	–	–	$P = 0.022$
Total Catch	$P = 0.0003$	–	$P < 0.0001$	$P = 0.015$	–	$P = 0.0005$	$P = 0.0018$	–	$P = 0.01$
Catch per Tow[2]									
Boats 1 and 2									
Normal Extension	38.71±29.30	13.85±18.30	124.87±120.84	4.73±5.84	2.91± 9.45				
Modified Extension	11.74±12.29	5.15± 6.89	121.43± 91.85	2.08±1.95	4.15±11.08				
Boat 3									
Normal Extension						45.63±50.63	5.14±5.02	19.43±52.55	0.02±0.03
Modified Extension						15.85±15.32	0.68±0.98	0.22± 0.63	3.78±6.98
Boat 4									
Normal Extension						12.76±12.47	2.61±3.16	0.08± 0.17	8.64±7.74
Modified Extension						15.85±15.32	3.88±3.91	2.30± 5.65	4.07±5.34

[1]Significant interaction terms with time-of-day and boat or net occurred no more frequently than expected by chance. [2]Mean±standard deviation. –, not significant at $\alpha = 0.05$.

Table 7

	25th Percentile	50th Percentile	75th Percentile	Mean Size
Loligo Squid				
Boats 1 and 2				
Normal Extension	7.88	9.38	11.00	9.60
Modified Extension	8.53	10.13	11.74	10.54
Boat 3				
Normal Extension	8.70	10.40	12.60	10.83
Modified Extension	9.44	11.25	13.13	11.38
Boat 4				
Normal Extension	10.44	12.17	13.67	12.27
Modified Extension	10.19	11.88	13.38	11.91
Scup				
Boats 1 and 2				
Normal Extension	11.44	13.25	15.72	13.85
Modified Extension	11.97	13.32	16.21	14.28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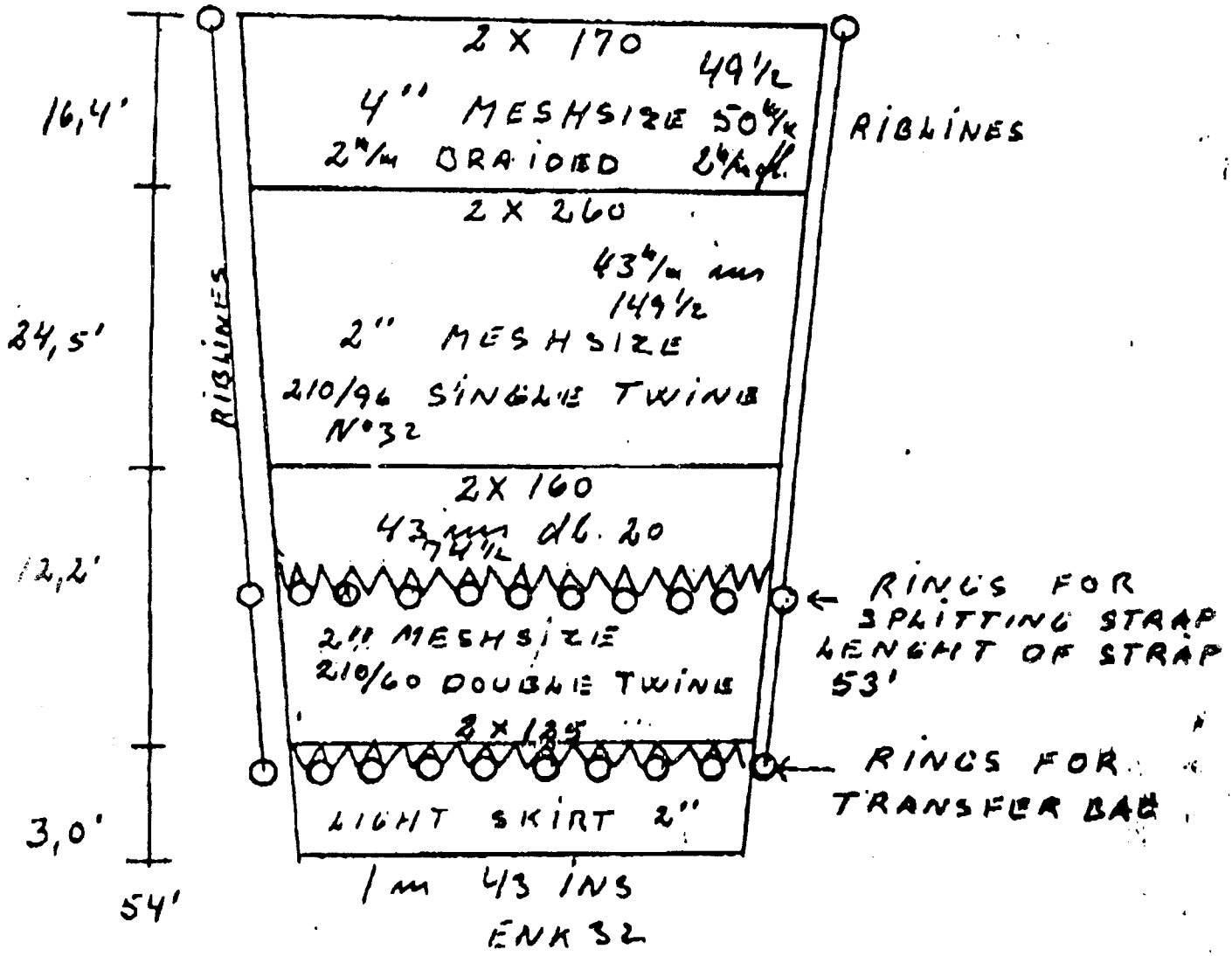
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