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Factors Influencing By-catch and Discard Rates: Analyses from Multispecies/Multifishery Sea Sampling

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Abstract

Factors influencing the species composition and magnitude of landings and discards were evaluated based on data from at-sea observations of 4 533 otter trawl tows. Data were collected from the USA mixed species otter trawl fisheries of the Georges Bank-Southern New England region, sampled during 1989–92. General linear models for main effects have related discard rates, total catch, and indices of species richness, diversity and evenness to temporal, spatial and operational variables associated with the fishing process (year, month, statistical reporting area, primary species sought, cod-end mesh size, vessel size, tow duration, total catch, total discards and depth). Discarding rates (proportion of the catch discarded) varied significantly both for individual species and for aggregated species by year, area, month, and target species. The effects of cod-end mesh size were variable, and confounded with year-class strength, particularly in the case of yellowtail flounder. Fisheries regulated by minimum fish and mesh sizes (e.g. for flounders and large gadoids) generally exhibited higher average discard rates and more variation than fisheries directed to species without such restrictions (e.g. for small pelagics, skates and others). The species composition and diversity of catches were significant functions of area, year, target species and month, as well as mesh size and tow duration. Year effects were more important for explaining variation in discard rates than total (multispecies) catches. This result is probably because large, partially-recruited year-classes differentially attract effort from other species targets, but most of the fleet landings are composed of mixed catches of species at moderate abundance levels. Multivariate approaches to analysis of sea sampling data offer important insights into the potential effectiveness of technological and area/time management measures for reducing fishery discards.

Key words: Bycatch, discards, gear selectivity, species composition

Introduction

By-catch and discarding have become critical fishery management issues worldwide (Schoning *et al*. 1992; Alverson *et al*., 1994). Harvesting practices that result in significant discard mortalities have important economic and ecological implications (Murawski, 1994). By-catches occur because of regulatory schemes that prevent certain animals from being retained (i.e. 'regulatory discards'), or because of economic infeasibility (i.e. 'economic discards'). The complexity of mixed-species fisheries often results in management strategies that compromise yields from individual species or métiers where mixed-target fisheries compete. Understanding the importance of various technical factors (e.g. mesh size, tow duration of trawl hauls), physical oceanographic factors (e.g. water depth, region), and biological factors (e.g. species mix, total catch, year-class strength) that influence discard rates are, then, key elements in designing management programs to maximize landings and minimize discards from such mixed-species systems.

Determining the proper gear to minimize discarding traditionally has involved mesh selection experiments (e.g. Smolowitz, 1983) to quantify the relationship between body size of the animal and net mesh size. Experiments are usually directed to individual target species of interest and are conducted under a design that attempts to fix, or at least randomize, all factors except the control variable of interest. Thus, for example, alternative mesh sizes are tested one at a time for their effects on the size composition of the catch of target species of interest. When many species are caught simultaneously, wide confidence limits are obtained around estimates of lengths at retention by the gear. Mesh retention studies can yield useful insights into the nature of the selection process for individual species of interest. However, because a mixture of species is usually caught, and fishing practices are not standardized, the relations between mesh size, discarding and total catch are complex and confounded.

The intent of this paper is to relate aspects of by-catch and discarding to spatial, temporal and operational characteristics of the fishing process. These analyses may be useful in the process of systematically reducing by-catch in multispecies fisheries. Data used for the study were derived from a sea sampling (observer) program initiated by the National Marine Fisheries Service in 1989 (Anderson, MS 1992). Because data have been obtained for a range of different mesh sizes, target species, years and levels of species abundance, interactions among factors influencing by-catch and discarding may be identified, and augment classic mesh retention experiments as aids to the development of strategies to reduce discard levels.

Materials and Methods

Exploratory analyses of the factors influencing by-catch and discard rates were undertaken based on the sea sampling database of the Northeast Fisheries Science Center. These analyses were restricted to the otter trawl fisheries of the Georges Bank and Southern New England regions (statistical reporting areas 521–613, inclusive; Fig. 1). Although a wider variety of gears and areas are sampled by the program, this subset was chosen because discarding problems have been identified for these fisheries in this region (Murawski, 1994).

Data collection and archival procedures for the sea sampling program are described in Anderson (MS 1992). Scientific observers determine the species composition, amount and disposition (kept or discarded) of all species or species groups caught on a tow-by-tow basis. The sampler determines location and gear characteristics for the tow. At the beginning of the trip, the captain is asked to identify the primary species (or group) sought. Data on various vessel and gear characteristics are also collected (Anderson, MS 1992).

The subset of variables describing attributes of each trawl tow and the resulting catch used in statistical analyses is described in Table 1. The designations of primary species sought contained in the analyzed subset are given in Table 2. The species catch for each tow was aggregated into 6 species groupings: 1) yellowtail flounder, 2) winter flounder, 3) skates, 4) other groundfish species, 5) other non-groundfish species, and 6) all species combined. These particular groupings were chosen in order to evaluate specific hypotheses associated with the discard of flatfishes in the region, and to conduct more general analyses. The kept and discarded portions of the catch were summarized separately for each of the six species groups. No

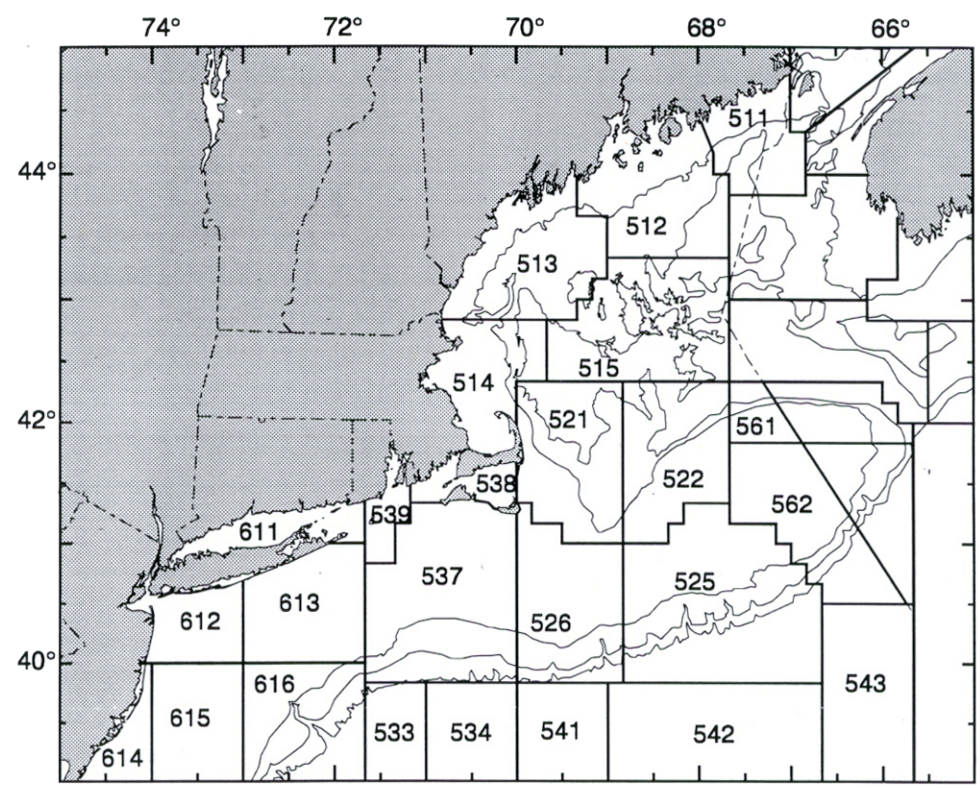

Fig. 1. Three-digit statistical reporting areas off the Northeast USA and Southeast Canada. Analyses of sea sampling data conducted herein used data from areas 521–613, inclusive.

TABLE 1. Summary of variables included in General Linear Models of factors influencing discard and by-catch, based on sea sampled otter trawl fishing trips in the Georges Bank, Southern New England area, 1989–92.

Variable	Description	Comments
Year	Year trawl tow was sampled	89, 90, 91, 92
Month	Month trawl tow was sampled	
Tons	Gross Registered Tonnage of Vessel	
Mesh	Cod-end mesh size of trawl	as reported by captain
Dur	Tow duration in tenths of hours	
Area	3-digit statistical area	Fig. 1
Prime	Primary species sought by trip	Table 2
Dep	Depth of tow (average)	
Totc	Total catch of all species	in pounds
Totd	Total discards of all species	in pounds
Totl	Total landings of all species	in pounds
Ytd	Total yellowtail flounder discards	in pounds
Ytl	Total yellowtail flounder landings	in pounds
Wfd	Total winter flounder discards	in pounds
Wfl	Total winter flounder landings	in pounds
Skd	Total skate discards	in pounds
Skl	Total skate landings	in pounds
Ogfd	Total other groundfish[1] discards	in pounds
Ogfl	Total other groundfish[1] landings	in pounds
Osd	Total other species[2] discards	in pounds
Osl	Total other species[2] landings	in pounds

[1] Other groundfish species are cod, haddock, pollock, summer flounder, American plaice, witch flounder, Acadian redfish and windowpane.
[2] Other species include all species or groups not explicitly mentioned above.

TABLE 2. Designations of primary species sought based on vessel captain's stated targets aboard sea sampling trips in the Georges Bank-Southern New England otter trawl fisheries, 1989–92.

Common Name	Scientific Name
Atlantic cod	*Gadus morhua*
Haddock	*Melanogrammus aeglefinus*
Silver hake	*Merluccius bilinearis*
Pollock	*Pollachius virens*
Witch flounder	*Glyptocephalus cynoglossus*
Yellowtail flounder	*Pleuronectes ferrugineus*
Winter flounder	*Pleuronectes americanus*
Summer flounder	*Paralichthys dentatus*
Flatfishes (not specified)	
Groundfish (not specified)	
Atlantic mackerel	*Scomber scombrus*
Butterfish	*Peprilus triacanthus*
Tuna (not specified)	
Pelagic fish (not specified)	
Skates	*Raja* spp.
Finfishes (not specified)	
American lobster	*Homarus americanus*
Squid (not specified)	
Species not identified	

attempt was made to separate regulatory from economic discards for the purposes of these analyses, although such an analysis would clearly be appropriate. These species groupings were made so as to illustrate both single- and multispecies responses, and to evaluate the aggregate responses of broad species groups of economic or ecological importance.

A total of 4 533 tows was analyzed. Summary statistics for some variables are given in Table 3. These tows were not uniformly distributed over the years, areas, months and primary species sought. Apart from the species groupings made from the tow catches, a number of descriptive variables were computed describing the degree of mixture of the tow-by-tow catches.

Indices of Species Richness, Diversity and Evenness

In order to evaluate the factors associated with the degree of species co-occurrence, a series of statistics evaluating the species richness, diversity and evenness (Ludwig and Reynolds, 1988) was calculated from individual catch data on a tow-by-tow basis:

Richness: Species richness was evaluated as the number of species (S) occurring within each trawl tow. A number of other richness indices were available, but were not applicable here because they have been developed for species numbers rather than weight indices.

Diversity: A wide variety of diversity indices are available; each variant is sensitive to different aspects of the catch:

N1 = exp(H') where H' is Shannon's diversity index:

$$H' = -\sum_{i=1}^{s} (p_i, \ln p_i)$$ where p_i is the proportion of species i in the sample and s is the number of species.

Shannon's index is 0 if there is only one species in the sample, and is maximum when all s species are equally represented. Exponentiation of H' gives the number of species that would, if each were equally common, produce the same H' as the sample.

N2 = $1/\lambda$ where λ is Simpson's diversity index:

$$\lambda = \sum_{i=1}^{s} p_i^2$$ where p_i is the proportion of species i in the sample.

Simpson's diversity index (varying from 0 to 1) is the probability that two individuals drawn at random belong to the same species. Diversity is low if the index is high. The inverse ($1/\lambda$) is commonly used since lower values imply lower diversity.

Evenness: Evenness indices measure the extent to which species catch is distributed over the species present in the sample. If all species are equally abundant, evenness is maximum.

TABLE 3. Summary of per haul statistics for selected variables calculated from 4 533 otter trawl tows observed in Southern New England and Georges Bank, 1989–92. (Diversity and evenness indices are defined in the text).

Variable	Mean	Standard Deviation	Coefficient of Variation
Total Catch (kg)	1 007	1 192	118.3
Tow Duration (hours)	2.37	1.11	46.7
Total % Discarded	50.74	23.01	45.3
Yellowtail Flounder			
% Discarded	27.27	24.34	89.3
Winter Flounder			
% Discarded	13.63	19.36	142.0
Number of Species	10.25	3.05	29.7
Shannon's Diversity (H')	1.30	0.40	30.7
Simpson's Diversity ()	0.41	0.17	41.7
N1 Diversity Index	4.05	1.54	38.0
N2 Diversity Index	3.01	1.22	40.5
E1 Evenness Index	0.57	0.16	27.8
E3 Evenness Index	0.34	0.15	45.2
E5 Evenness Index	0.62	0.14	22.5

$$E1 = H'/\ln(S)$$
$$E2 = \exp(H')/S$$
$$E3 = \exp(H')-1/S-1$$

Indices E1–E3 are sensitive to the number of species in the sample. Indices E4 and E5 (below) are effectively independent of sample size and the numbers of species:

$$E4 = 1/\lambda \div \exp(H')$$
$$E5 = [(1/\lambda) - 1] \div [\exp(H') - 1]$$

E4 can be thought of as the ratio of very abundant to abundant species and tends towards 1 as one species becomes dominant, whereas E5 approaches 0 as a single species becomes dominant, thus E5 is a preferred measure (Ludwig and Reynolds, 1988). The above indices were evaluated as linear functions of the categorical and continuous independent variables describing location, time and fishing operations as described below.

General Linear Models

General linear models (GLMs) were fitted using the dependent and independent variables described in Table 1. These GLMs used a combination of categorical and continuous independent variables. In all cases only main effects were tested in order to undertake a wide range of exploratory analyses (Table 4). In some cases, models incorporating interaction effects were evaluated when specific questions of interpretation of main effects model results arose. All models were fitted using SAS proc GLM. Type II–IV sums of squares were used in hypothesis testing, owing to the unbalanced nature of the data (Searle, 1987). Transformations of catches ($\log_{ln}$ n+1) and percentages (arcsin square root) had little influence on overall results, and are thus not reported here.

Results for a number of the GLMs performed are summarized in Table 4. For each model fitted, the following results are reported: (1) total R^2 from the model fit (in all cases the models were significant, owing to the very large sample sizes), (2) significance and F-values associated with the categorical independent variables, and (3) significance and estimated model coefficients associated with continuous independent variables. The F-statistics for significant main effects were used to provide a description of relative importance of various factors to the dependent variables tested. Likewise, for categorical variables, estimates of relative model coefficients for each level of effect (i.e., year, month, area, etc.) were reported. The set of models evaluated here represents an exploratory rather than exhaustive analysis.

Results and Discussion

For each GLM fitted, the overall model and all the effects of categorical independent variables (year, month, area, primary species sought) were statistically significant (Table 4). This was due primarily to the very large sample sizes, and the wide contrasts among the various levels of the categorical variables. The model fits explained between 7 and 51% of the tow-by-tow variation in the dependent variables. Given the large variation inherent in tow-by-tow data, the overall amount of variation explained by some models was relatively large.

Three of the model fits provided an evaluation of the effects of independent variables on discard rates of yellowtail flounder, winter flounder, and all species taken. A significant portion of the sea sampling program has been devoted to evaluating yellowtail flounder discarding in the study area. A total of 1 948 sea sampled tows contained yellowtail catch data. The overall discard rate was 27%, but the rate varied significantly by year (Fig. 2; Table 4). The decline in yellowtail discarding over the four years was due to the recruitment of a strong 1987 year-class, followed by very weak cohorts. For yellowtail discard rate, the F-level for the year effect was largest, followed by area and month (Table 4). Surprisingly, the effect of mesh was not-significant in the main effects GLM. The mesh sizes contained in the samples ranged from 104 to 155 mm. Since a strong cohort was moving through the fishery, large amounts of discard occurred in the early years, with all mesh sizes. A second GLM incorporating year and mesh main effects and a Year*Mesh interaction indicated a significant Year*Mesh effect. The hypothesis tested was that larger skate catches (landings + discards) would reduce the selectivity of the mesh and result in higher yellowtail discard rates. This is a reasonable assumption since the predominant species taken in the directed yellowtail flounder fishery is little skate (Murawski, 1991). As a continuous variable in the GLM, skate catch had no significant influence on yellowtail discard rate (Table 4), although the effect was significant but negative for winter flounder.

The all-species discard rate was significantly negatively related to cod-end mesh sizes from 104 to 155 mm (Fig. 3; Table 4). It should be noted, however, that cod-end mesh sizes were not measured on sea sampled tows, and in some cases liners were used, which are not accounted for in these summaries. Nevertheless, the overall pattern was clear.

Results summarized in Fig. 4 are the estimated coefficients relating all species discard rate to the

TABLE 4. Description of General Linear Models relating aspects of discarding and by-catch (dependent variables) in the Georges Bank-Southern New England otter trawl fisheries to categorical and continuous independent variables. Independent variables are described in Table 1. For each general linear model, the total R^2 explained by the model is given, along with the significance (Probability $F>F_{critical}$) of each main effect. The second line for each model gives the F-values relating to categorical variables, and the estimated model coefficients for continuous variables. Variables not included or not estimated for each model are blank.

Dependent	Independent Variables											
	Categorical					Continuous						
Variable	R^2	Year	Month	Area	Prime	Mesh	Tons	Dur	Totc	Totd	Dep	Skd+Skl
Total Catch	0.51	0.00	0.00	0.00	0.00	0.05	0.00	N.S.				
[F-values/Coefficients]		5.6	4.7	10.2	202.4	411.5	4.35	–				
Total Discard Rate	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
[F-values/Coefficients]		48.6	6.8	15.0	31.5	-5.64	0.019	-6.36				
Yellowtail Flounder Discard Rate	0.44	0.00	0.00	0.00	0.00	N.S.	N.S.	0.02	0.00	0.00	0.01	N.S.
[F-values/Coefficients]		54.6	12.0	18.6	8.8	–	–	1.79	-0.001	0.004	0.136	
Winter Flounder Discard Rate	0.48	0.00	0.00	0.00	0.00	N.S.	0.00	N.S.	N.S.	0.00	N.S.	0.00
[F-values/Coefficients]		43.8	8.83	26.2	13.7	–	-0.03	–	–	0.004	–	-0.003
Number of Species (N0)	0.25	0.00	0.00	0.00	0.00	0.01	0.00	0.00			0.01	
[F-values/Coefficients]		14.5	16.6	10.7	17.5	-0.82	-0.003	0.65			0.004	
Shannon's Diversity (H')	0.23	0.00	0.00	0.00	0.00	0.00	N.S.	0.00				
[F-values/Coefficients]		7.5	14.4	10.0	13.4	-0.13	–	0.09				
Simpson's Diversity (λ)	0.22	0.00	0.00	0.00	0.00	0.01	N.S.	0.00			0.00	
[F-values/Coefficients]		4.5	12.3	8.8	11.0	0.03	–	-0.04			0.0003	
N1 Diversity [exp(H')]	0.21	0.00	0.00	0.00	0.00	0.00	N.S.	0.00				
[F-values/Coefficients]		10.3	15.4	11.7	13.3	-0.55	–	0.34				
N2 Diversity [1/λ]	0.19	0.00	0.00	0.00	0.00	0.00	N.S.	0.00			N.S.	
[F-values/Coefficients]		8.1	11.6	11.9	11.0	-0.31	–	0.25			–	
E1 Evenness [H'/ln(N0)]	0.24	0.00	0.00	0.00	0.00	0.01	N.S.	0.00			N.S.	
[F-values/Coefficients]		10.2	10.3	8.8	10.3	-0.03	–	0.02			–	
E2 Evenness [N1/N0]	0.18	0.00	0.00	0.00	0.00	N.S.	0.03	N.S.			0.02	
[F-values/Coefficients]		13.5	5.8	11.6	10.6	-0.02	8.8e-5	–			-0.0002	
E3 Evenness [N1–1/N0-1]	0.21	0.00	0.00	0.00	0.00	0.02	0.04	0.00			0.00	
[F-values/Coefficients]		12.9	8.3	10.5	10.2	-0.03	8.7e-5	0.01			-0.003	
E4 Evenness [N2/N1]	0.07	0.00	0.00	0.04	0.00	0.01	N.S.	N.S.			0.00	
[F-values/Coefficients]		5.5	3.5	1.7	4.3	0.02	1.4e-5	–			-0.0002	
E5 Evenness [N2–1/N1–1]	0.13	0.01	0.00	0.00	0.00	N.S.	0.05	0.00			0.00	
[F-values/Coefficients]		4.0	7.2	5.8	5.6	–	7.3e-5	0.02			-0.0005	

principal species sought. Several patterns emerge. Flatfish fisheries generally produced proportionally greater discards, and fisheries for slender bodied groundfish (e.g., silver hake) and pelagics produced relatively lower discard rates (the exception is for non-specified pelagics as the primary species sought, but this fishery was represented by very few observations in the data set). Otter trawl fisheries for pelagics and silver hake may produce higher proportions of target

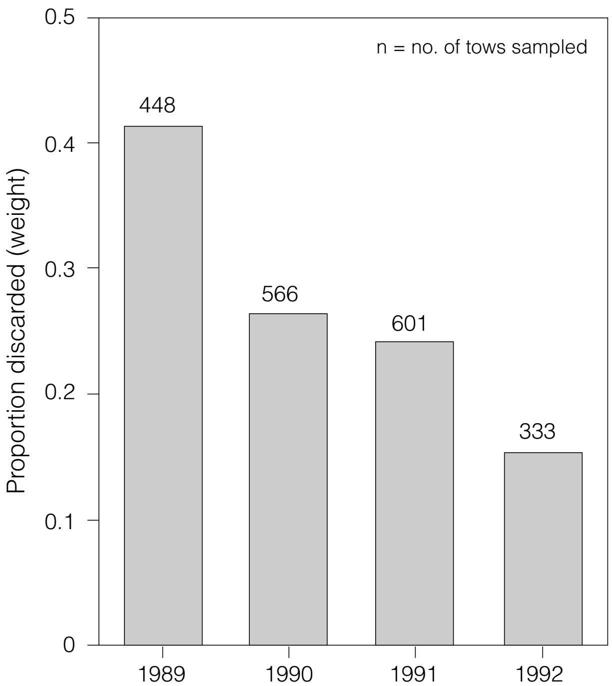

Fig. 2. Discard rate (pounds discarded/landed+discards) of yellowtail flounder sampled aboard commercial otter trawlers, 1989–92. Data are mean discard rates for given numbers of tows sampled at sea.

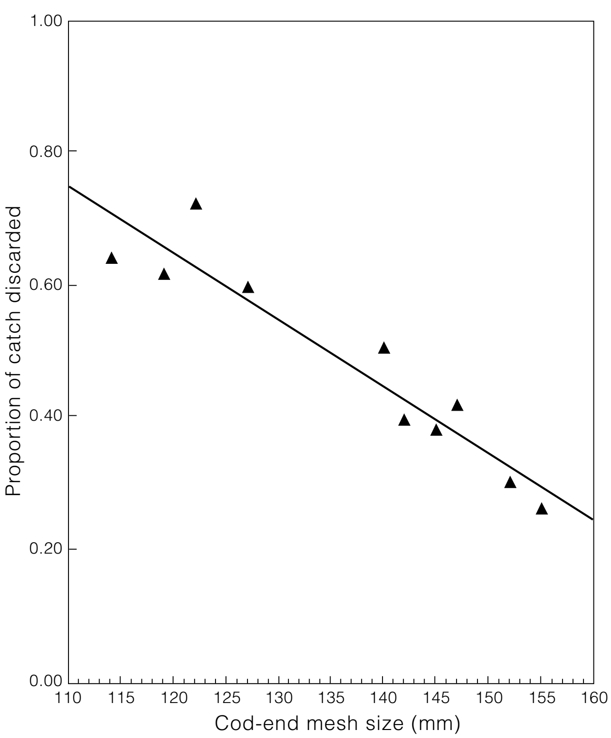

Fig. 3. Effects of cod-end mesh size on the proportion of trawl tow catch discarded, for all species caught. Data are from otter trawl fishery sea sampling off the Northeast USA, 1989–92, and are mean discard rates in various mesh size categories.

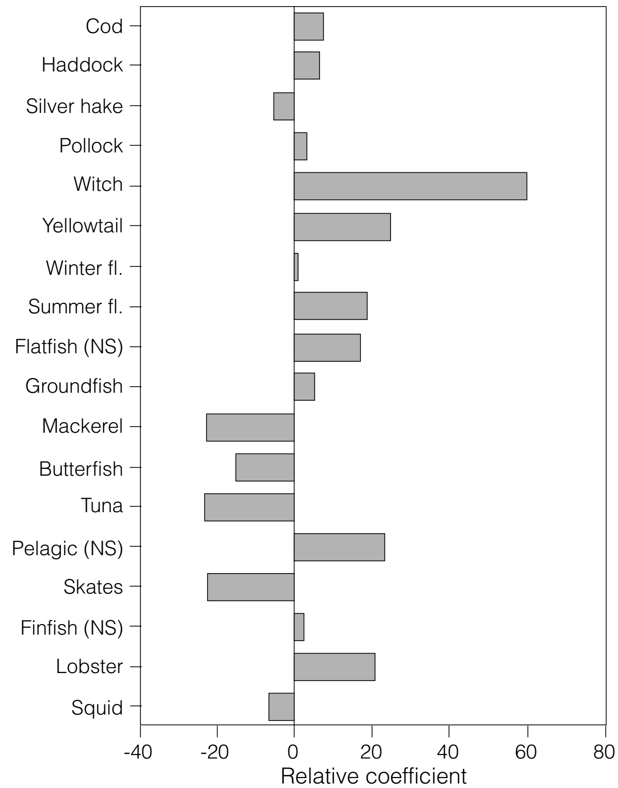

Fig. 4. Estimated relative coefficients for each primary species category, with respect to its effect on total (all species) discard rate. Coefficients are scaled relative to a coefficient of 0.0 for primary species = other species caught (Table 2).

species, than do the flatfish fisheries. The directed skate fishery also appeared to produce relatively low discard rates, although here also the number of tows sampled was low. In general, however, skates were discarded in quantity in most trawl fisheries: the overall discard rate for skates was 89%. The main factors influencing the all species discard rate were year, primary species sought, mesh size, and tow duration. The effect of tow duration on overall discard rate was negative (longer tows resulting in lower discard rates), which should be a topic for further detailed investigation.

The most important factors associated with the total catch (landings + discards) were the primary species sought, and the gross registered tonnage of the vessel. Other factors were relatively unimportant, including tow duration.

An important question in designing mitigation measures for by-catch and discard is the extent to which various operational characteristics of the fishery may influence the catch of non-target species. By limiting directed fishing to times and places where resources are segregated, the quantity of unintended catch could potentially be reduced. Murawski (1991) noted that factors such as tow duration may act to integrate patchy distributions of more-or-less segregated resources into what appear to be mixtures of species. Thus, the implication is that shorter tow times may result in less diverse catches, and perhaps a higher proportion of target species. Variation in species diversity (N2) was primarily related to tow duration (Fig. 5); the effect was positive. In general, the effects of mesh size were significant and negative, implying that larger mesh sizes resulted in lower species diversity. Although categorical effects were significant in determining species richness, diversity and evenness, these effects were modest, and overall the amounts of variance explained in these model fits was much lower than for discard rates. In general, tow duration was positively related to species evenness (Table 4), and shallower depths produce more even distributions of catches among the species.

These exploratory models identify some potentially important relationships among fishing practices and the temporal patterns in the availability of species. The significant effects of year-class size (aliased as a year effect) on discard rate are well documented (Anonymous, MS 1985; Reeves, MS 1990). Year effects in these analyses were much more influential in explaining total discard rate than in explaining total catch (Table 3). This was due to the highly mixed nature of tow and trip catches and the considerable target species shifting evident in these fisheries. The effect of mesh size on multispecies discard rates raises interesting questions about mechanisms operating over such a wide range of available species of various sizes and relative abundance levels. The effects of mesh size and tow duration on discard rates and species diversity/richness should spur the design of further analyses to evaluate factors likely to contribute to reduced by-catch and discarding. One tendency resulting from lower overall groundfish and flounder catch rates off the Northeast USA has been an increase in overall tow duration. If tow duration is indeed positively related to diversity, the by-catch levels for the fleet will increase as tow duration increases in response to lower catch rates. This is generally consistent with the anecdotal observation of less single species targeting in the otter trawl fisheries, and more effort resulting in 'target mixtures'. The relationship between tow time and overall discard rate was clearly positive for yellowtail flounder, but negative for all species catches. The confounding influences of other main effects or aggregation over all species in the GLM models need to be evaluated in more detail. The strong area and month effects in all models imply that season/area effects could potentially be exploited in an overall strategy to reduce discard/by-catch.

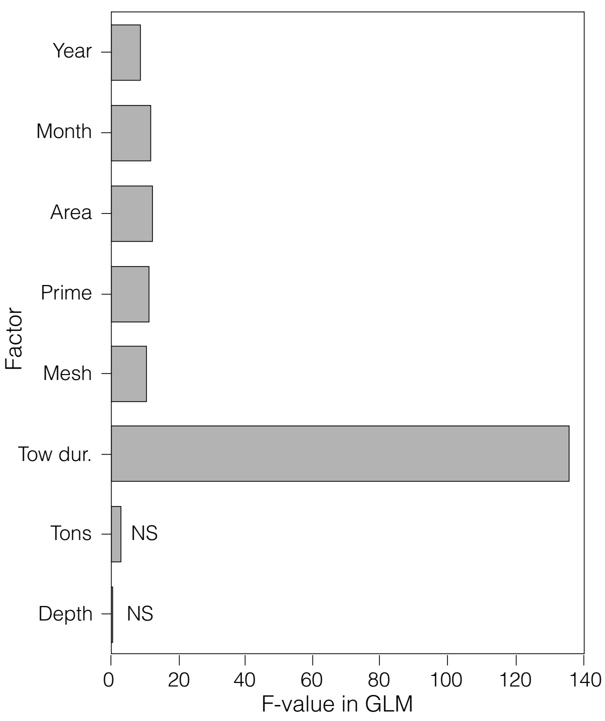

Fig. 5. F-ratios from general linear models fitted to sea sampling data collected from otter trawl fisheries off the Northeastern USA, 1989–92. Dependent variable is species diversity (N2 index, see Table 1). N.S. indicates non-significant (P>0.05) factor.

An important factor not considered explicitly in these analyses is the reason particular species are discarded. Discarding result either from regulations (e.g. prohibited species, sizes or amounts) or because of economic reasons (unmarketable species, sizes or individuals). For the yellowtail flounder and winter flounder directed fisheries, discards of target species were clearly regulatory in nature, owing to the selection of sub-legal sized individuals by prevailing mesh sizes. In general, fisheries sizes, for cod, haddock, pollock, flounders, regulated with minimum fish or meshes exhibited substantially higher aggregate discard rates than those fisheries without such regulations (mackerel, butterfish, tuna, skates, silver hake and squid; Fig. 4). For species such as skates, dogfishes and others, which can represent a significant fraction of the catches in fisheries targeted at more valuable species, the reasons for discarding are clearly economic.

Regulatory discards are controllable, to a degree, based on factors such as mesh size, area fished and others influencing their magnitude. Reducing economic discards will require incentives and regulations well beyond those associated with where and how fishing gear is deployed. An obvious elaboration of these analyses is to explicitly assess factors associated with the two types of discards, and information on the reasons for discarding particular species is recorded on a tow-by-tow basis from the sea sampling program.

Apart from the regulatory issues associated with by-catch, these preliminary analyses have significant implications for the design of future analyses and gear retention experiments. Given the association of catch levels, discard rates and operational characteristics (such as tow time and mesh size), the interactions of these factors may result in lower actual benefits as opposed to those calculated from typical mesh selection studies. Future mesh studies should account for variations among operational characteristics (e.g., tow time) and variations in the biological community being fished in a factorial experimental design, and the analysis of mesh retention should be considered in a multivariate framework.

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References

ALVERSON, D. L., M. H. FREEBERG, S. A. MURAWSKI, and J. G. POPE. 1994. A global assessment of fisheries by-catch and discards. *FAO Fish. Tech. Pap.*, No. 339.

ANDERSON, J. MS 1992. Sea sample database system (SSDBS) users manual. NMFS, NEFSC, Woods Hole, Massachusetts 02543 (unpublished mimeo).

ANONYMOUS. MS 1985. Report of the working group on methods of fish stock assessments, 20–26 November, 1985, Copenhagen. *ICES C. M. Doc.*, No. Assess:10.

LUDWIG, J. A., and J. F. REYNOLDS. 1988. Statistical ecology, a primer on methods and computing. John Wiley & Sons. New York. 337 p.

MURAWSKI, S. A. 1991. Can we manage our multispecies fisheries? *Fisheries* (*Bethesda*), **16**(5): 5–13.

1994. Opportunities in by-catch mitigation. In: Conserving U.S. Fisheries: A national symposium on the Magnuson Act. R. Stroud (ed). National Coalition for Marine Conservation, Savannah, Georgia.

REEVES, S. A. MS 1990. Linear modelling of discard data from Scottish demersal fisheries. *ICES C. M. Doc.*, No. G:53.

SCHONING, R. W., R. W. JACOBSEN, D. L. ALVERSON, T. H. GENTLE, and J. AUYONG (eds.). 1992. Proceedings of the National Industry By-catch Workshop, February 4–6, 1992, Newport, Oregon (available from Natural Resources Consultants, 4055 21st W., Seattle, WA 98199).

SEARLE, S. R. 1987. Linear models for unbalanced data. John Wiley and Sons, New York. 536 p.

SMOLOWITZ, R. J. 1983. Mesh size and the New England ground fishery – applications and implications. *NOAA Tech. Rep.*, NMFS SSRF-771, 60 p.

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