An Analysis of Some Factors Affecting the Catchability of Fish by Bottom Trawls

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Abstract

The data from 515 comparative tows by the research vessels *Albatross IV* and *Belogorsk* using the Yankee No. 36 and the modified Yankee No. 41 bottom trawls during day and night were analyzed for 23 species groups (including all species together). In general, demersal species were significantly more vulnerable to trawl gear during night than during day, while the converse was true for semi-pelagic species. The fishing power of the No. 41 trawl was significantly greater (and never significantly lower) than the fishing power of the No. 36 trawl for 15 of the 23 species groups. The relative fishing power of the trawls was significantly affected by the towing vessel for six of the species groups.

Introduction

Research bottom-trawl surveys along the Northwest Atlantic coast of the USA are intended to provide an index of abundance of species of the region. Catch per unit of fishing effort in these surveys is affected by the catchability[1] of fish by the fishing gear being used and also by the density of the fish in the area sampled. Therefore, the fishing power (relative catchability of fish) of the two trawls predominantly used by research vessels in the area was estimated so as to allow comparison between survey results using either of these gears.

The fishing power of a trawl depends on the towing vessel (size, power, speed, etc.), physical factors (light conditions, sea state, bottom type, currents, etc.) and trawl design. The factorial experiment described below provided an adequate set of data to estimate the fishing power of both trawls when towed by two vessels of different sizes during periods of daylight and darkness.

USA autumn bottom-trawl surveys were initiated in 1963 using the No. 36 Yankee trawl. Spring bottom-trawl surveys were begun in 1968 using the same gear, but a modified Yankee No. 41 high-opening trawl has been used since 1973. A detailed description of the trawls is given by Bowman (MS 1976) along with some of the reasons for changing from the No. 36 trawl to the larger modified No. 41 trawl. Grosslein (1969) described the methodology of the USA bottom-trawl surveys.

Gear Comparison Experiment

Gear comparison studies were conducted during the autumn of 1973-75 using the research vessels *Albatross IV* and *Belogorsk*. The *Albatross IV* [56 m in length, 853 gross tons (metric), 1,000 horsepower] is operated by the National Oceanic and Atmospheric Administration and assigned to the Northeast Fisheries Center of the National Marine Fisheries Service, USA. The *Belogorsk* (69 m, 2,213 gross tons, 1,600 horsepower) is operated by the Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO), Kaliningrad, USSR.

The vessels operated simultaneously at randomly selected locations within a 65-km^2 area. All tow locations were in waters south of Martha's Vineyard centered at 40°50'N and 70°20'W during 1973-74 but in 1975 about half of the tows were made on the southern part of Georges Bank centered at 41°24'N and 66°53'W, with the other half at the previous location. The order in which the two gears were towed was also selected randomly. The towing speed was about 6.4 km per hour. The direction of towing was toward the next randomly selected station. Tows were made with all combinations of ship and gear during day and night periods (dawn and dusk excluded). Data from 32 days of gear comparison studies are considered in this paper. Sixteen tows (2 gears × 2 vessels × 2 time periods × 2 replicates) were planned for each of the first 30 days of the experiment and 24 tows were implemented during the last 2 days of the experiment by increasing the number of

[1] Catchability is defined as the fraction of a fish population which is caught by a defined unit of fishing effort (Ricker, 1975). The unit of fishing effort considered in this paper is one 30-min tow. The term "vulnerability" is equivalent to catchability but is usually applied to separate parts of a population such as particular size categories.

replicates to three. During the experiment 13 tows were not completed or were disregarded because of factors beyond the control of the experimenters. Therefore the results of this paper are based on 515 tows ($30 \times 16 + 2 \times 24 - 13$). A more complete account of the gear comparison experiments is given by Bowman (MS 1976).

Method of Analysis

Using the approach of Robson (1966), the following model was applied to the data from gear comparison experiments:

$$C = \alpha_i \beta_j \gamma_k (\alpha\beta)_{ij} (\alpha\gamma)_{ik} (\beta\gamma)_{jk} \phi P \tilde{\epsilon} \qquad (1)$$

where C is catch per tow; P is population density; ϕ is the catchability coefficient under standard conditions (to be defined); $\tilde{\epsilon}$ is a log-normally distributed random variable; α_i, β_j and γ_k are multiplicative gear, diel and ship factors respectively; $(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$, and $(\beta\gamma)_{jk}$ are multiplicative gear-diel, gear-ship, and diel-ship interaction factors respectively.

Fishing with the No. 36 Yankee trawl by the *Albatross IV* during daylight was arbitrarily chosen as the standard situation, and therefore α_1 (No. 36 trawl), β_1 (day period) and γ_1 (*Albatross IV*) all equal 1.0. The interaction terms also equal 1.0 unless both subscripts are 2. The goal of the analysis is to estimate α_2 (No. 41 trawl), β_2 (night period), γ_2 (*Belogorsk*), $(\alpha\beta)_{22}$ (No. 41 trawl-night period interaction), $(\alpha\gamma)_{22}$ (No. 41 trawl-*Belogorsk* interaction), and $(\beta\gamma)_{22}$ (night period-*Belogorsk* interaction).

Since population size is unknown, fluctuations in P cannot be accounted for directly in the model. An alternate approach (in the absence of a measure of population abundance) is to compare C for various combinations of gear, ship, and light level within the same day of the experiment, assuming that the size of the population being sampled (within the 65-km^2 sample area) is relatively constant over a brief time interval. Following this approach, P is replaced by $\psi_l \bar{P}$ where $\bar{P}$ is the average population size over all days of the experiment and ψ_l is the ratio of P for day l to $\bar{P}$. The product of $\bar{P}$ and ϕ can be replaced by θ. Therefore, making the substitutions and taking the natural logarithm (ln) of both sides of Equation (1):

$$\ln C = \ln\alpha_i + \ln\beta_j + \ln\gamma_k + \ln(\alpha\beta)_{ij} + \ln(\alpha\gamma)_{ik} + \ln(\beta\gamma)_{jk} + \ln\theta + \ln\psi_l + \ln\tilde{\epsilon} \qquad (2)$$

where l ranges from 1 to 32, and i, j and k each equals 1 or 2. Using the convention $X' = \ln X$ for any symbol X, and rewriting Equation (2) as a multiple linear regression problem with dummy variables,

$$C' = \theta' + \alpha' X_1 + \beta' X_2 + \gamma' X_3 + (\gamma\beta)'(X_1X_2) + (\alpha\gamma)'(X_1X_3) + (\beta\gamma)'(X_2X_3) + \sum_{m=1}^{31} \psi_m X_{m+3} + \epsilon' \qquad (3)$$

where

$$X_1 = \begin{cases} 0 \text{ for No. 36 trawl} \\ 1 \text{ for No. 41 trawl} \end{cases}$$

$$X_2 = \begin{cases} 0 \text{ for daylight} \\ 1 \text{ for darkness} \end{cases}$$

$$X_3 = \begin{cases} 0 \text{ for } \textit{Albatross IV} \\ 1 \text{ for } \textit{Belogorsk} \end{cases} \qquad (4)$$

$$X_{m+3} = \begin{cases} 1 \text{ for day } m \\ -1 \text{ for day 32} \\ 0 \text{ for otherwise} \end{cases}$$

and ϵ' is normally distributed.

The number of dummy variables used for each factor (gear, diel, ship and day) is one less than the number of levels of that factor. This is necessary so that the design matrix of the model is non-singular and thus invertible, allowing the parameters of Equation (3) to be estimated. For the gear, diel and ship factors, the number of parameters and dummy variables is reduced to 1 (thus the subscripts of α', β' and γ' are dropped), by assuming a standard and only estimating departures from the standard. For the day factor, ψ_m is considered a departure from the average condition over all days of the experiment, and therefore

$$\sum_{m=1}^{32} \psi'_m = 0 \quad \text{or} \quad \psi'_{32} = -\sum_{m=1}^{31} \psi'_m \qquad (5)$$

The designation of dummy variable in Equation Set (4) is equivalent to Equation (5).

The parameters of Equation (3) were estimated by stepwise multiple regression using the Statistical Package for the Social Sciences (SPSS) (Nie *et al.*, 1975). Independent variables were only included in Equation (3) if they reduced enough residual variance to be statistically significant at the 5% level. The analysis was conducted for species caught in significant amounts during the experimental tows and for all species together with the catch expressed in numbers and weight. Data for some species were analyzed because of commercial and recreational interests, even though they were a minor component of the catch.

In practice, the catch of all of the species considered was 0 for some of the 515 tows, so that the ln C was sometimes undefined. This problem is usually avoided by adding 1.0 to C, resulting in C′ greater than or equal to 0. While it is necessary to add some constant to C when the parameters to be estimated are ratios, the parameter estimates are affected by the constant which is added. This is especially true when C is the same order of magnitude as the constant that is added to it. For example, the ratio of 2 to 4 is substantially different from the ratio of 3 to 5. Therefore, 0.1 was added to C to assure that C′ was always defined, while minimizing the distortion of parameter estimates. A smaller value than 0.1 was not used because this would have had an undesirable effect on the residuals from regression as will be discussed later.

Let $\hat{X}'$ be an unbiased estimate of X′ with a normal distribution. The antilogarithm of $\hat{X}'$ (where X′ = ln X) is a biased estimate of X since the expected value of $e^{\hat{X}'}$ is

$$E(\hat{X}') = e^{X' + \sigma^2/2} = Xe^{\sigma^2/2} \qquad (6)$$

where σ is the variance of $\hat{X}'$ (Brownlee, 1965). Therefore

$$E(e^{\hat{X}' - \sigma^2/2}) = X \qquad (7)$$

is an unbiased estimator. Since σ^2 is estimated by s^2, an approximately unbiased estimate of X is obtained by taking the antilogarithm of $\hat{X}' - s^2/2$. This method was used to estimate α, β, γ, $(\alpha\beta)$, $(\alpha\gamma)$ and $(\beta\gamma)$ from the regression coefficients estimated for Equation (3). The 95% confidence intervals of these coefficients were obtained by taking the antilogarithm of the end points of the 95% confidence intervals of α', β', γ', $(\alpha\beta)'$, $(\alpha\gamma)'$ and $(\beta\gamma)'$.

Results

About 85 species were caught in the 515 tows considered in this paper. Of these, 22 species groups (or species), which comprised 91% of the total catch, were analyzed as described in the previous section. The analysis was also applied to the catch of all species combined. The mean catch per tow in weight and numbers by species group for each cell of the experiment (combination of gear, diel and ship factors) is given in Table 1. Since the number of observations is nearly equal for each cell, the mean catch over several cells can be approximated by averaging values available in Table 1.

Statistically significant (at the 5% level)[2] estimates of the parameters of Equation (1) are given in Table 2. The 95% confidence limit of these estimates (labeled as minimum and maximum estimate) and the percentage of the variation in transformed catch explained by Equation (3) are also given in Table 2. Some of the reduction in variability is attributed to the ψ terms of the model, but these are not reported in the table because they are only applicable to fishing at a specific location on a particular day in the past.

The estimates in Table 2 are based on the assumption that ϵ' [of Equation (3)] is an independent (not autocorrelated) normally distributed random variable with a constant variance at all levels of C′. Parameter estimates of Equation (3) are the minimum variance linear (linear function of set of C′) unbiased estimates even for a non-normal distribution of ϵ' (Gauss-Markoff theorem; see Graybill, 1961). Furthermore, tests of significance and confidence intervals are robust when ϵ' has a non-normal distribution and linear models are particularly robust to non-normal residuals and a non-constant variance when the number of observations in each cell is equal (Scheffe, 1963). The number of observations in each cell of this analysis is nearly equal.

A test for autocorrelation of residuals from a regression equation was derived by Durbin and Watson (1951). The Durbin and Watson test statistic (d) has an expected value of 2.0, with lower values indicating positive autocorrelation and higher values indicating negative autocorrelation. An exact test of the significance of d is not available, but an approximate test is provided by Durbin and Watson for up to 100 observations and five independent variables. The regression equations, on which Table 2 is based, are for 515 observations and usually more than 10 independent variables. Extrapolating from the work of Durbin and Watson (1951; their table 5), a significant (5% level) degree of autocorrelation appears indicated for $d < 1.5$ or $d > 2.5$. The Durbin and Watson statistic for each regression equation is given in Table 2. Based on these statistics, it appears that residuals tend to be positively autocorrelated (only 6 of 48 are greater than 2.0) but individual values of d seldom appear significant at the 5% level. This tendency for residuals to be mildly autocorrelated probably results in little underestimation of the width of confidence intervals because of the large number of degrees of freedom associated with the analysis.

The residuals from each regression equation were examined visually in order to detect violations of the

[2] Significance levels are probably slightly exaggerated when coefficients of a linear model are fit by stepwise multiple regression. For the same reason, the width of confidence intervals is probably slightly underestimated.

TABLE 1. Mean catch per tow: (A) in weight in centigrams (100 g); and (B) in numbers.

	Albatross IV				*Belogorsk*					
	Day		Night		Day		Night		Species	% of tows
	No. 36	No. 41	No. 36	No. 41	No. 36	No. 41	No. 36	No. 41	mean	present
(A) Bluefish, *Pomatomus saltatrix*	35.2	35.2	16.0	4.3	22.5	43.4	5.5	3.9	20.6	29
Butterfish, *Poronotus triacanthus*	99.7	132.3	2.9	7.3	68.5	71.0	1.8	4.8	48.2	71
Cancer crabs, *Cancer* spp.	5.3	10.7	4.9	10.9	0.1	20.8	0.1	26.7	9.9	60
Dogfish, *Mustelus canis* and *Squalus acanthias*	36.3	157.7	48.1	80.0	67.8	81.6	44.0	68.0	72.6	59
Flounder, 4-spot, *Paralichthys oblongus*	1.5	3.8	59.6	67.3	0.6	5.6	32.2	72.3	30.5	73
Sand, *Scophthalmus aquosus*	0.8	1.3	27.9	19.3	0.5	1.4	14.3	24.8	11.3	52
Summer, *Paralichthys dentatus*	9.4	14.3	7.2	8.1	9.7	18.6	2.6	5.8	9.4	18
Winter, *Pseudopleuronectes americanus*	10.5	18.8	33.4	35.4	8.8	18.1	16.6	56.6	24.8	77
Yellowtail, *Limanda ferruginea*	11.7	16.9	60.1	63.3	5.9	13.3	29.7	77.4	34.9	85
Goosefish, *Lophius americanus*	13.0	21.0	21.4	49.5	5.9	24.2	14.7	58.2	26.0	43
Hake, Red, *Urophycis chuss*	0.0	0.8	10.2	7.5	0.1	0.5	8.5	8.1	4.5	34
Silver, *Merluccius bilinearis*	13.0	22.3	41.0	180.0	9.8	23.5	18.6	158.8	58.6	84
Herring, Round, *Etrumeus sadina*	54.0	38.8	0.0	0.3	76.2	60.3	0.1	0.0	28.2	24
Lobster, *Homarus americanus*	9.4	22.8	8.7	18.3	10.1	20.3	7.6	22.5	14.9	58
Sculpin, Longhorn, *Myoxocephalus octodecemspinosus*	0.3	0.6	10.6	18.8	0.4	0.6	12.9	22.2	8.3	39
Scup, *Stenotomus chrysops*	16.5	9.7	17.7	27.9	10.4	15.7	8.4	18.3	15.6	61
Sea raven, *Hemitripterus americanus*	1.5	1.9	3.9	6.4	1.3	2.5	2.6	6.7	3.4	23
Sea robin, Common, *Prionotus carolinus*	0.1	0.2	8.3	6.6	0.1	0.1	2.9	6.6	3.1	28
Skate, Big, *Raja ocellata*	2.2	3.4	11.0	4.0	3.1	6.8	23.6	34.3	11.0	19
Little, *Raja erinacea*	15.4	31.5	147.3	237.0	10.9	44.8	71.6	383.0	117.9	86
Squid, *Illex illecebrosus*	1.6	2.4	1.2	1.6	1.1	1.2	1.6	1.4	1.5	32
Loligo pealei	272.6	275.8	50.0	34.6	157.5	293.8	42.8	43.5	145.1	74
All species	655.8	913.6	596.2	895.7	638.0	1,012.2	375.2	1,118.7	771.7	100
(B) Bluefish, *Pomatomus saltatrix*	1.0	1.1	0.5	0.1	0.7	5.6	0.2	0.1	1.1	29
Butterfish, *Poronotus triacanthus*	304.5	420.0	10.3	15.5	197.5	279.6	6.7	11.5	155.0	71
Cancer crabs, *Cancer* spp.	6.9	13.6	7.1	11.4	0.1	19.7	0.2	30.8	11.2	60
Dogfish, *Mustelus canis* and *Squalus acanthias*	5.2	56.5	8.1	22.2	23.7	18.0	5.0	11.6	18.8	59
Flounder, 4-spot, *Paralichthys oblongus*	0.8	2.1	33.3	36.2	0.4	2.5	17.8	41.1	17.0	73
Sand, *Scophthalmus aquosus*	0.3	0.6	12.2	7.8	0.1	0.7	5.3	11.1	4.8	52
Summer, *Paralichthys dentatus*	0.4	0.6	0.4	0.4	0.3	0.8	0.1	0.4	0.4	18
Winter, *Pseudopleuronectes americanus*	3.0	5.6	11.2	11.5	2.7	6.2	5.4	19.8	8.2	77
Yellowtail, *Limanda ferruginea*	4.5	6.7	25.6	26.1	2.3	5.7	11.7	34.8	14.8	85
Goosefish, *Lophius americanus*	0.4	1.0	1.1	1.9	0.2	0.9	0.4	2.5	1.0	43
Hake, Red, *Urophycis chuss*	0.2	0.5	11.6	7.1	0.1	0.4	8.8	8.1	4.6	34
Silver, *Merluccius bilinearis*	9.5	18.1	112.4	303.5	13.6	21.4	82.6	296.4	108.1	84
Herring, Round, *Etrumeus sadina*	156.2	140.2	0.1	0.5	211.4	314.2	0.4	0.1	101.0	24
Lobster, *Homarus americanus*	1.4	2.7	1.0	3.1	1.3	3.2	0.7	2.6	2.0	58
Sculpin, Longhorn, *Myoxocephalus octodecemspinosus*	0.2	0.5	9.8	15.7	0.1	0.5	11.3	19.3	7.2	39
Scup, *Stenotomus chrysops*	8.7	4.8	17.4	16.4	4.7	7.8	5.8	14.0	10.0	61
Sea raven, *Hemitripterus americanus*	0.2	0.4	0.8	1.4	0.3	0.4	0.8	1.8	0.8	23
Sea robin, Common, *Prionotus carolinus*	0.1	0.2	4.0	3.2	0.1	0.1	1.7	3.6	1.7	28
Skate, Big, *Raja ocellata*	0.2	0.3	1.9	0.4	0.2	1.1	3.9	5.4	1.7	19
Little, *Raja erinacea*	3.0	7.0	29.9	54.4	2.0	9.5	14.4	85.8	25.9	86
Squid, *Illex illecebrosus*	3.7	3.3	0.6	0.9	2.8	1.9	0.8	0.8	1.8	32
Loligo pealei	3,193.1	2,368.8	144.2	113.9	2,751.7	3,652.5	218.9	170.1	1,560.6	74
All species	4,475.8	3,633.5	455.6	667.7	5,985.0	6,518.7	414.8	788.4	2,830.7	100

assumption of a constant variance and normal distribution. The range of residuals about the expected transformed catch (C') appears independent of the level of C', and thus there is no evidence that the assumption of a constant variance is violated.

Two examples of the distribution of residuals from regression equations reported in this paper are given in Fig. 1 and 2, which indicate that the distribution is truncated in the lower left quadrant. This occurs because the lowest possible value of C' is -2.30 (ln 0.1) which corresponds to a species being absent from a tow. Therefore, all observations of zero catch fall on the straight line described by: Residual = -2.30 - Expected (C'). When a species is absent from a substantial number of tows, the distribution of residuals looks particularly abnormal because so many observations lie along this line. While the robustness of the regression model is probably adequate to allow residual distribution with some irregularities (such as Fig. 1), the abnormality in Fig. 2 casts doubt on parameter estimates and particularly on confidence limits. Species for which residuals have an extremely abnormal appearance are indicated in Table 2 by an asterisk. In general, these species were absent from 50% or more of the tows.

The abnormal appearance of residuals could have been reduced by using the ln (C + 1.0) transformation instead of ln (C + 0.1), since the gap between a catch of 0 and 1 fish in a tow is much smaller for the former than the

TABLE 2. Fishing power coefficients estimated by fitting Equation (3) and retransforming parameters by Equation (7). Minimum and maximum estimates indicate endpoints of 95% confidence intervals.

		α			β			γ			$(\alpha\beta)$			$(\alpha\gamma)$			$(\beta\gamma)$			%	Durbin-
Species		Min. est.	est.	Max. est.	Min. est.	est.	Max. est.	Min. est.	est.	Max. est.	Min. est.	est.	Max. est.	Min. est.	est.	Max. est.	Min. est.	est.	Max. est.	SS reduced	Watson Statist.
Bluefish *	Number	—	—	—	0.29	0.36	0.44	—	—	—	—	—	—	—	—	—	—	—	—	18.1	1.92
	Weight	—	—	—	0.14	0.19	0.27	—	—	—	—	—	—	—	—	—	—	—	—	18.0	1.92
Butterfish	Number	—	—	—	0.048	0.06	0.09	0.52	0.70	0.97	—	—	—	—	—	—	—	—	—	71.2	1.60
	Weight	1.05	1.35	1.78	0.084	0.11	0.14	0.50	0.64	0.84	—	—	—	—	—	—	—	—	—	60.0	1.66
Cancer crabs	Number	3.92	5.72	8.70	—	—	—	0.12	0.18	0.53	—	—	—	10.80	18.31	33.80	—	—	—	56.0	1.30
	Weight	2.60	3.59	5.10	—	—	—	0.27	0.37	0.53	—	—	—	4.29	6.73	11.20	—	—	—	44.0	1.18
Dogfish	Number	1.07	1.40	1.88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	48.1	1.66
	Weight	1.03	1.45	2.11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37.2	1.76
Flounder																					
4-spot	Number	1.23	1.63	2.22	32.11	39.42	48.95	0.39	0.52	0.77	—	—	—	1.29	1.92	3.00	—	—	—	74.5	1.64
	Weight	1.15	1.48	1.95	26.05	31.35	38.10	0.46	0.59	0.78	—	—	—	1.31	1.89	2.81	—	—	—	75.6	1.61
Sand	Number	1.31	1.67	2.15	8.96	11.38	14.69	—	—	—	—	—	—	—	—	—	—	—	—	52.6	1.67
	Weight	1.10	1.37	1.74	7.07	8.84	11.21	—	—	—	—	—	—	—	—	—	—	—	—	50.8	1.67
Summer *	Number	1.06	1.23	1.42	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	50.1	2.11
	Weight	1.06	1.31	1.64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	47.7	2.13
Winter	Number	1.63	2.02	2.55	2.61	3.25	4.10	—	—	—	—	—	—	—	—	—	—	—	—	58.9	1.67
	Weight	1.32	1.86	2.70	1.98	2.78	4.04	—	—	—	—	—	—	—	—	—	—	—	—	46.7	1.69
Yellowtail	Number	1.31	1.76	2.41	4.58	5.66	7.08	0.40	0.54	0.74	—	—	—	1.25	1.88	2.98	—	—	—	60.5	1.82
	Weight	1.28	1.73	2.42	3.57	4.45	5.63	0.37	0.51	0.71	—	—	—	1.28	1.97	3.20	—	—	—	60.2	1.86
Goosefish *	Number	1.97	2.45	3.08	1.45	1.80	2.27	—	—	—	—	—	—	—	—	—	—	—	—	30.6	1.85
	Weight	2.38	3.35	4.86	1.51	2.12	3.07	—	—	—	—	—	—	—	—	—	—	—	—	20.4	1.79
Hake																					
Red *	Number	—	—	—	4.42	5.56	7.09	—	—	—	—	—	—	—	—	—	—	—	—	55.8	1.52
	Weight	—	—	—	2.35	2.84	3.46	—	—	—	—	—	—	—	—	—	—	—	—	39.9	1.62
Silver	Number	1.53	2.36	3.85	11.32	15.53	21.91	0.26	0.41	0.67	—	—	—	1.18	2.15	4.41	—	—	—	50.0	1.48
	Weight	1.06	1.61	2.60	2.24	3.18	4.68	0.33	0.47	0.69	1.66	2.69	4.70	1.15	1.86	3.25	—	—	—	55.1	1.64
Herring *, round	Number	—	—	—	0.11	0.16	0.23	—	—	—	—	—	—	—	—	—	—	—	—	32.3	1.56
	Weight	—	—	—	0.32	0.41	0.52	—	—	—	—	—	—	—	—	—	—	—	—	20.6	1.65
Lobster	Number	2.12	2.66	3.37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	39.3	2.01
	Weight	2.05	2.72	3.70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27.2	2.02
Sculpin *, Longhorn	Number	1.29	1.61	2.04	8.03	10.05	12.76	—	—	—	—	—	—	—	—	—	—	—	—	65.0	1.75
	Weight	1.13	1.34	1.61	3.38	4.08	4.96	—	—	—	—	—	—	—	—	—	—	—	—	57.0	1.68
Scup	Number	—	—	—	1.67	2.17	2.87	—	—	—	—	—	—	—	—	—	—	—	—	55.1	1.56
	Weight	—	—	—	1.53	1.96	2.57	0.35	0.50	0.73	—	—	—	—	—	—	—	—	—	46.8	1.59
Sea raven *	Number	1.10	1.28	1.49	1.30	1.50	1.75	—	—	—	—	—	—	1.25	2.02	3.51	—	—	—	63.0	1.77
	Weight	1.07	1.25	1.46	1.07	1.24	1.45	—	—	—	—	—	—	—	—	—	—	—	—	59.0	1.74
Sea robin *	Number	—	—	—	3.42	4.18	5.17	0.55	0.71	0.92	—	—	—	1.20	1.59	2.16	—	—	—	47.0	1.54
	Weight	—	—	—	2.33	2.77	3.32	—	—	—	—	—	—	—	—	—	—	—	—	37.0	1.50
Skate *																					
Big	Number	—	—	—	1.08	1.41	1.87	—	—	—	—	—	—	—	—	—	1.10	1.50	2.09	27.6	1.58
	Weight	—	—	—	1.38	1.77	2.30	1.01	1.29	1.68	—	—	—	—	—	—	—	—	—	79.0	1.74
Little	Number	3.15	3.98	5.12	8.82	11.16	14.34	—	—	—	—	—	—	—	—	—	—	—	—	57.7	1.51
	Weight	3.23	4.14	5.41	9.39	12.05	15.75	—	—	—	—	—	—	—	—	—	—	—	—	55.1	1.59
Squid																					
Illex *	Number	—	—	—	0.43	0.58	0.71	—	—	—	—	—	—	—	—	—	—	—	—	57.9	1.59
	Weight	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	55.9	2.00
Loligo	Number	—	—	—	0.04	0.05	0.07	—	—	—	—	—	—	—	—	—	—	—	—	83.3	1.56
	Weight	—	—	—	0.25	0.38	0.58	0.25	0.37	0.58	0.35	0.57	0.99	1.22	2.00	3.52	—	—	—	58.9	1.48
All species	Number	—	—	—	0.25	0.32	0.42	—	—	—	—	—	—	—	—	—	0.49	0.67	0.94	55.0	1.47
	Weight	1.54	1.86	2.27	—	—	—	—	—	—	1.03	1.28	1.62	1.29	1.77	2.50	—	—	—	28.0	1.60

* Extreme violations of underlying assumptions of analysis for these species.

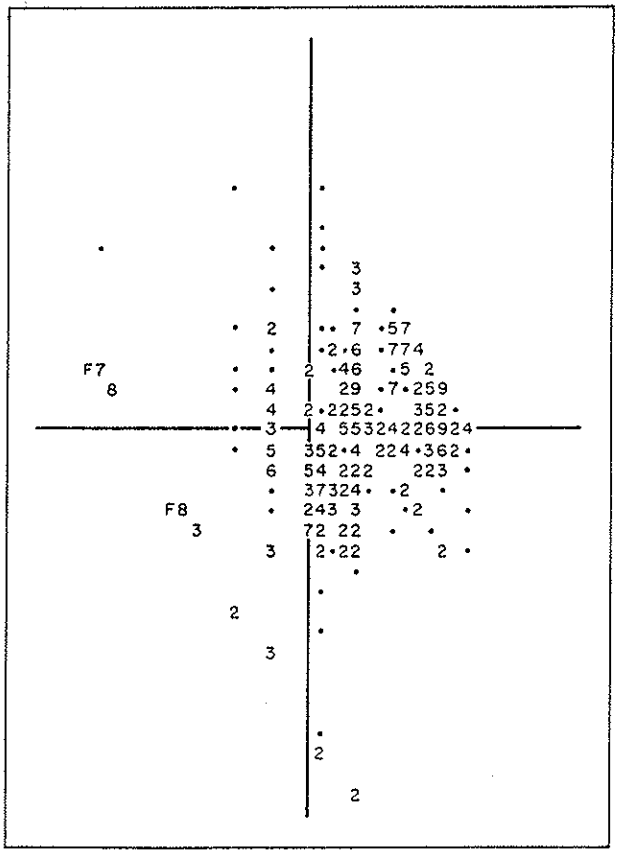

Fig. 1. Residuals (vertical line) *versus* expected value of C′ (horizontal line) for *Loligo*. Numbers indicate number of residuals at approximately the same location on the plot with A, B, C, D, E and F corresponding to 10, 11, 12, 13, 14 and 15 or more residuals.

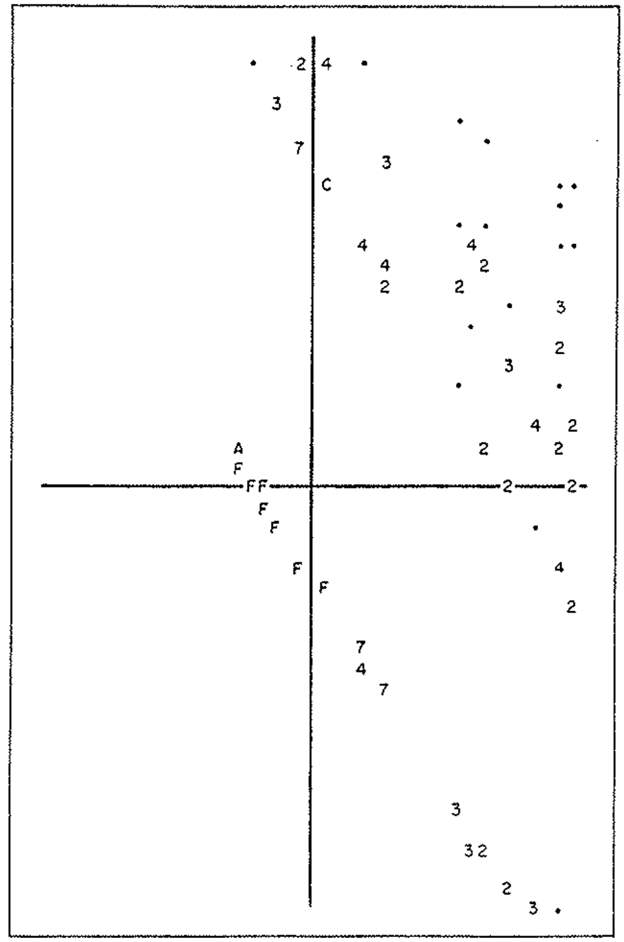

Fig. 2. Residuals (vertical line) *versus* expected value of C′ (horizontal line) for fluke. Numbers indicate number of residuals at approximately the same location on the plot with A, B, C, D, E and F corresponding to 10, 11, 12, 13, 14 and 15 or more residuals.

latter transformation (ln 1.1 − ln 0.1 = 2.4, ln 2.0 − ln 1.0 = 0.69). The serious bias that results from using the ln (C + 1.0) transform for small values of C was noted under the methods section of the paper. The use of a smaller constant than 0.1 in the transformation would result in still further abnormality of residuals (using 0.01, ln 1.01 − ln 0.01 = 4.62).

Discussion

Significant day-night differences in catch are indicated for 19 of the 23 species groups considered (including all species grouped together). The differences ranged from nearly a 40-fold increase in catch of fourspot flounder (in numbers) to a decrease in catch of *Loligo* (in numbers) by a factor of nearly 20 when comparing night to day. Generally groundfish (flounders, skate, sculpin and others) were more vulnerable to both trawls at night than during the day while the opposite was true of semi-pelagic species (squid, butterfish, round herring and bluefish). Silver hake which are often assumed to be semi-pelagic were more vulnerable at night as is characteristic of groundfish. The increased vulnerability of groundfish at night may reflect nocturnal prowling and feeding or decreased avoidance, while the increased vulnerability of semi-pelagic species during the day could result from light inhibition which concentrates fish near the bottom. It is noteworthy that lobsters and *Cancer* crabs, which are believed to be more active at night, were equally catchable during day and night. The differences in vulnerability between day and night are seldom affected by the gear and/or the ship involved. Significant diel-gear or diel-ship interactions were only detected for silver hake, *Loligo* and big skate.

The diel factors (β) for some species were substantially different for catch in numbers and in weight, indicating that the vulnerability of fish as a function of weight changes with light level. For *Loligo*, the mean weight of individuals in the catch was seven times greater for night tows than for day tows, but the mean weight of silver hake was five times greater during day than at night.

Catchability with the No. 41 trawl was significantly higher than with the No. 36 trawl when towed by the *Albatross IV* for 15 of the 23 species groups. The largest gear factor was 5.72 (for catch in numbers of *Cancer* crabs). The gear factors for goosefish and little skate were also larger than 3.0. A gear factor of 1.15 would result from the greater width (at the wings) of the No. 41 if all other factors are equal. Because of the variability of the data considered in this study, factors between 0.80 and 1.20 were unlikely to be detected as being statistically significant at the 5% level.

Catchability with the No. 36 trawl was often lower (8 of 23 species groups) when towed by the *Belogorsk* than when towed by the *Albatross IV*. Catchability with the No. 36 trawl when towed by *Belogorsk* was less than half the catchability of the same net towed by *Albatross IV* for *Cancer* crabs, silver hake, scup and *Loligo*. On the other hand, catchability with the No. 41 trawl was significantly higher when towed by the *Belogorsk* than when towed by the *Albatross IV* for 6 of the 23 species groups, as indicated by gear-ship interaction factors $(\alpha\gamma)$. The value of $(\alpha\gamma)$ for *Cancer* crabs in numbers caught was 18.31. Other statistically significant values of $(\alpha\gamma)$ were about 2. The mechanisms that result in the greater fishing power of the *Albatross IV* than of the *Belogorsk* when towing the No. 36 trawl for several species and the converse relationship when towing the No. 41 trawl are unknown.

The fishing power coefficients estimated here allow comparison of survey results for data collected either during day or night, with the No. 36 or No. 41 trawl, or with the *Albatross IV* or *Belogorsk*. Obviously, when these coefficients are applied, they introduce an unknown amount of additional imprecision. The available data were inadequate for examination of the seasonal variability in fishing power coefficients. Areal variability was examined (between Georges Bank and southern New England). No significant difference between areas was indicated, but the experiment was not intended to address this problem and therefore this result is inconclusive.

Based on the substantial data considered in this paper, the relative fishing power of two vessels and two bottom trawls during day and night was estimated to within ± 1/3 (at the 5% level) for several species. Due to violations in regression assumptions, a much lesser degree of confidence is realistic for species absent from a majority of tows. The results indicate that, for most species, more variability in catch is explained by diel variations than by gear type or towing vessel and that the fishing power of trawl gears is often dependent on the towing vessel.

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