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Factors Affecting Estimates of Relative Catchabilities of Fishing Units in ICNAF Subarea 5 and Statistical Area 6

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INTRODUCTION

At the ICNAF Special Meeting of Experts on Effort Limitations in March 1973, it was recommended that member countries examine the "magnitude of the error associated with the factors involved in setting a fishing effort regulation". As one approach to this problem analyses of variance studies were used to investigate the effects of year, month, species and area factors in addition to country and gear tonnage categories in estimating relative catchabilities. This procedure makes possible the calculation of the reduction in total variation of relative catchabilities accounted for by the various factors in the linear model used.

METHODS

Data Base: Nominal landings and effort for designated main species (or species group) sought categories are reported by ICNAF associated countries fishing in Subarea 5 and Statistical Area 6. These data are published in Table 4 of the ICNAF Statistical Bulletin. Landings from Divisions 5Ze, 5Zw and 6A of finfish only, but excluding catches by gear other than fixed, and of the large pelagic fishes (i.e. tuna, billfish), menhaden, and sharks (other than dogfish), in 1970 and 1971 were used in this study. In instances where no "main species sought" category was indicated, or where landings were attributed to a "mixed" fishery the monthly landings by gear were assigned to one of the "species caught" categories in Table 4 on a basis of simple plurality (Assessment Subcommittee Report, ICNAF Summ Doc 73/1). All reported landings were thus grouped by species or species group fisheries.

Summary totals over all species fisheries within months and over all months within species fisheries were made to obtain two data sets, one containing yearly totals by species fisheries for each area, country, gear-tonnage class and one for 1971 data only containing monthly totals over all species for each area, country gear-tonnage class category.

The following model was used for the analyses:

$$y'_{i'j'k'\ell'm} = \exp\Big(M + \sum_{i=1}^{I} X_{1im} B_{1i} + \sum_{j=1}^{J} X_{2jm} B_{2j} + \sum_{k=1}^{K} X_{3km} B_{3k} + \sum_{\ell=1}^{L} X_{4\ell m} B_{4\ell} + e_{i'j'k'\ell'm}\Big) \quad (1)$$

where $y'_{i'j'k'\ell'm}$ = CPUE of the mth observation at the i'-j'-k'-ℓ' level such that

$1 \le i' \le I$

$1 \le j' \le J$

$1 \le k' \le K$

$1 \le \ell' \le L$,

M = overall mean

B_{1i} = ith level of nation factor, $\sum_{i=1}^{I} B_{1i} = 0$

B_{2j} = jth level of gear factor, $\sum_{j=1}^{J} B_{2j} = 0$

B_{3k} = kth level of area factor, $\sum_{k=1}^{K} B_{3k} = 0$

$B_{4\ell}$ = ℓth level of month factor, $\sum_{\ell=1}^{L} B_{4\ell} = 0$

and

$$X_{np} = \begin{cases} 1 & \text{if } p = \begin{cases} i' & \text{when } n = 1 \text{ or} \\ j' & \text{when } n = 2 \text{ or} \\ k' & \text{when } n = 3 \text{ or} \\ \ell' & \text{when } n = 4 \text{ or} \end{cases} \\ 0 & \text{otherwise} \end{cases}$$

$e_{i'j'k'\ell'm}$ = error term of the mth observation at the i'j'k'ℓ' level and is assumed to be independent of i, j, k, ℓ, and M and has a $N(0,\sigma^2)$ distribution.

The $\log_e$ transform of (1) is an example of the general linear hypothesis model (Pheng, 1967) and specifically is a four-way analysis of variance model with the implicit assumption that all interaction terms are insignificant. The nature of the data results in many cells with no observations and thus the design is unbalanced, and the standard procedures developed for fitting balanced designs do not apply. The following procedure was used to estimate the parameters of the model and to test their significance. Using matrix notation the log transform of (1) becomes

$$X\beta = Y + E \qquad (2)$$

where

$$Y = \begin{pmatrix} \log y'_{11111} & \dots & \log y'_{IJKL1} \\ \vdots & & \vdots \\ \log y'_{1111m} & \dots & \log y'_{IJKLm} \end{pmatrix}; \quad E = \begin{pmatrix} e_{11111} & \dots & e_{IJKL1} \\ \vdots & & \vdots \\ e_{1111m} & & e_{IJKLm} \end{pmatrix},$$

$$X = (1 : X_1 : X_2 : X_3 : X_4),$$

$$X_j = \begin{matrix} X_{111} & \dots\dots & X_{1I1} \\ \vdots & & \vdots \\ X_{1Im} & \dots\dots & X_{1Im} \end{matrix} \quad \text{for m replicates}$$

$$\beta = \begin{pmatrix} M \\ B_{11} \\ \vdots \\ B_{1I} \\ \vdots \\ B_{L1} \\ \vdots \\ B_{4L} \end{pmatrix} \qquad (3)$$

The estimate of β is obtained by multiplying (2) by X', the transpose of X, and then by, $(X'X)^{-1}$, the inverse of $X'X$, yielding

$$\hat{\beta} = (X'X)^{-1} X'Y \qquad (4)$$

(σ^2) is estimated by

$$\hat{\sigma}^2 = (Y'Y - \beta'X'Y') \; / \; (M - (I+J+K+L) + 3) \qquad (5)$$

Additional notation is required to describe the calculation of sums of squares of the effects of the model.

$$\text{Let } Z_n = (1 : X_1 : X_2 : \dots X_4)$$

where n = factor of interest, $1 \le n \le 4$ and

$$X_j = \begin{pmatrix} 0 & \dots & 0 \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ 0 & \dots & 0 \end{pmatrix} \text{ for } j = n.$$

Also, let

$$\beta_n = \begin{pmatrix} M \\ B_{11} \\ \cdot \\ \cdot \\ \cdot \\ B_{1I} \\ \cdot \\ \cdot \\ \cdot \\ B_{4L} \end{pmatrix}$$

where M is the overall mean, and

$$B_{jp} = \begin{pmatrix} 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{pmatrix} \text{ for } j = n \text{ and all } p.$$

(X_n) and B_n are then deleted from their respective matrices under the hypothesis that there is no nth effect. The estimates of sums of squares are given by

Effect	Degrees of Freedom	Sums of Squares
Country	I-1	$\beta'X'Y - \beta_1'Z_1'Y$
Gear	J-1	$\beta'X'Y - \beta_2'Z_2'Y$
Area	K-1	$\beta'X'Y - \beta_3'Z_3'Y$
Month	L-1	$\beta'X'Y - \beta_4'Z_4'Y$
Error	M - (I+J+K+L) + 3	$Y'Y - \beta'X'Y$

(6)

An estimate of the log of relative catchability is obtained by

$$R'_{ijkl} = \hat{B}_{1i} + \hat{B}_{2j} + \hat{B}_{3k} + \hat{B}_{4l} - B_{1s_i} - B_{2s_j} - B_{3s_k} - B_{4s_l} \quad (7)$$

where

R'_{ijkl} = log relative catchability for the ith nation, jth gear, kth area, and lth month or species

s_i = value of i for the standard gear

. .
. .
. .

s_l = value of l for the standard gear

An estimate of the variance of R'_{ijkl} is given by

$$V(\hat{R}'_{ijkl}) = \hat{\sigma}^2(L'(X'X)^{-1}L) \quad (8)$$

where

$$L = \begin{pmatrix} 0 \\ \cdot \\ \cdot \\ \cdot \\ -\hat{\beta}_{.1s_i} \\ \cdot \\ \cdot \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ \hat{\beta}_{.1i} \\ \cdot \\ \cdot \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ -\hat{\beta}_{.4s_l} \\ \cdot \\ \cdot \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ \hat{\beta}_{4l} \end{pmatrix}$$

Approximately 95% confidence limits about R'_{ijkl} are given by

$$R'_{ijk\ell} \pm 2\sigma = R'_{ijk\ell} \pm 2\,(V(R'_{ijk\ell}))^{1/2}$$

The antilog of R'_{ijkl}, namely R_{ijkl}, is an estimate of relative catchability. These estimates tend to be biased downward for large values because of the log transformation. The estimates of the confidence limits about R_{ijkl} present a reasonably accurate view of the magnitude of the confidence limits about an unbiased estimate of relative fishing power. It should be noted that because of the unbalanced nature of the design, estimates of R_{ijkl} for combinations of i, j, k, and l not present in the data are tenuous.

A second model was included in this study. The ℓ factor - month - of the model was substituted by a species factor, and an area X species interaction term was included in the analysis of variance. The sum of squares table for this model is identical to (6) except for the error term which is split into an interaction term plus a new error term. Then two terms can be written as -

$$\sum_{ijk\ell m} (y_{..k\ell.} - y_{..k..} - y_{...\ell.} + y_{....})^2 \tag{9}$$

$$\text{and } (Y'Y - \beta'X'Y - \sum_{ijk\ell m} (y_{..k\ell.} - y_{..k..} - y_{...\ell.} + y_{....})^2)$$

which sums to the error term of the previous model. The former sum in (9) has (K-1)(L-1) degrees of freedom, while the latter sum has M+3-(I+J+K+L)-(K-I)(L-I) degrees of freedom.

RESULTS AND DISCUSSION

The first analysis concerned itself with area, month, country and gear-tonnage factors. The total catch (of all species) and effort in 1971 within the blocks of data defined by these factors was used as the dependent variable (excluding the segments discussed above).

The results of this analysis of variance indicate that all main factor effects were significant except areas (Table 1). An area-month interaction might be expected to be significant, but examination of this and other interactions are not apt to be meaningful because of the unbalanced nature of the data.

The model explains about 68% of the variation of log catch per effort in ICNAF areas 5Ze, 5Zw, and 6A for 1971. The country factor accounts for 9%, gear 57% and month only 2%. This result suggests that not too much is to be gained by including other factors in the model.

The 95% confidence limits about individual relative catchabilities are within about 40% of the estimates. The 68% confidence limits would be approximately ± one standard deviation and in general would be within about 20% of the estimates, i.e. the component of variation is about this much.

The seasonal analysis of variance included year, species, country, and gear-tonnage class factors (otter trawlers only). Data for 1970 and 1971 were used with the basic variable being the sum of catch and effort over months within the blocks. A year-gear interaction was included. The results (Table 2) again suggest that the latter two factors account for the largest portion of the variation in log catch per effort. The species effect was also significant but the year and year-gear effects were not. It is encouraging that the year-gear term is not significant because this suggests that the gears have remained the same between 1970-1971 in relation to each other and thus might be expected to do so in the future. While the species factor is significant it only accounts for about 2% of the deviations from the model while the country factor accounted for 14% and the gear-tonnage class factor for 29%. The model accounted for 46% of the total variance. In comparison with the first analysis, which included months as a factor, seasonal effects are apparently important.

The conclusions from this study indicates that for the purpose of standardizing fishing effort units, the most critical factor is that due to vessel gear-tonnage class category; the country factor is also important. Month and species are factors of lesser importance. The latter two were not considered together in the same analysis and it is possible that the monthly factor may, in part, be a result of shifts to different species, i.e. they may interact to produce a significant effect for some combinations. The absolute magnitude of monthly deviations from the overall (averaged over areas) does not appear great and much of the variation appears due to very few months (Table 3).

In 14 of the 15 cases where there were observations in January, that month had the highest relative catchability. The extent to which these single high values influence the range is illustrated by examining the ratio of the difference between the upper extreme value and the next highest value to the range (Table 4). For these cases where there were at least four monthly observations, the average ratio was 44% (Table 4). Thus, unless fleets are capable of extreme concentration of fishing effort, little would be gained by regulating fishing effort using monthly standardization coefficients.

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Table 1. Analysis of variance of 1971 catch per effort data in ICNAF areas 5Ze, 5Zw, and 6A.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F[1]
Country	8	30.21	3.78	13.48**
Gear	13	185.75	14.29	51.**
Area	2	.34	.17	.61
Month	11	6.93	.63	2.25*
Error	374	104.79	.28	

*Significant at 95% level of confidence

[1]**Significant at 99% level of confidence

Table 2. Analysis of variance of 1970-1971 catch per effort data in ICNAF areas 5Ze, 5Zw, and 6A.

Source	Degrees of Freedom	Sums of Squars	Mean Squares	F[1]
Country	7	102.37	14.62	34.13**
Gear	9	200.98	22.33	52.12**
Year	1	0.35	0.35	0.81
Species	6	12.16	2.03	4.73**
Year-Gear	9	6.01	.67	1.56
Error	887	380.10	.43	

[1]**Significant at 99% level of confidence

Table 3-0. Relative catchabilities averaged over areas by gear and country.

	Otter Trawler Side						
Gear:	0-50 T	51-150 T	151-500 T			501-900 T	
	COUNTRY						
Month	USA	USA	USA	Canada	Russia	USSR	Poland
Jan.	0.65	0.99	0.60		0.82	1.03	0.99
Feb.	0.43	0.66	0.40		0.52	0.77	0.65
Mar.	0.48	0.73	0.44		0.59	0.77	0.74
Apr.	0.49	0.76	0.45		0.61	0.80	0.73
May	0.48	0.73	0.44	0.61	0.58	0.77	0.70
June	0.54	0.82	0.50	0.69	0.63	0.85	0.79
July	0.43	0.67	0.40	0.56	0.53	0.69	0.63
Aug.	0.38	0.57	0.35	0.48	0.46	0.61	0.55
Sept.	0.45	0.68	0.40	0.57	0.55	0.72	0.65
Oct.	0.40	0.61	0.37	0.51	0.48	0.62	0.59
Nov.	0.41	0.63	0.38	0.53	0.50	0.66	0.61
Dec.	0.43	0.67	0.39	0.56	0.53	0.70	0.64

Table 3-1. Relative catchabilities averaged over areas by gear and country.

	Otter Trawler Stern						
Gear:	0-50 T	51-150 T	151-500 T	501-900 T	901-1800 T		
	COUNTRY						
Month	USA	USA	USA	Canada	Poland	Ger. F.R.	Japan
Jan.	2.15	0.69	1.13		4.16	5.45	
Feb.	1.48	0.45	0.75	0.75	2.75		
Mar.	1.67	0.52	0.84	0.84	3.09		1.38
Apr.	1.65	0.52	0.86		3.07		
May	1.66	0.52	0.83	0.83	2.96		
June	1.86	0.57	0.93	0.93	3.32		
July	1.50	0.45	0.75	0.76	2.64		
Aug.	1.25	0.40	0.65	0.65	2.28	3.06	
Sept.	1.54	0.48	0.77	0.76	2.70	3.63	
Oct.	1.32	0.43	0.69	0.69	2.32	3.24	
Nov.	1.43	0.43	0.72	0.72	2.55	3.36	
Dec.	1.50	0.53	0.76	0.76	2.68	3.45	

Table 3-2. Relative catchabilities averaged over areas by gear and country.

Gear: Otter Trawler Stern Over 1800 T

Month	COUNTRY USSR	Poland	Ger. F.R.	Romania	Japan	Bulgaria
Jan.	5.03	4.78	6.18	0	0	0
Feb.	3.32	0	0	0	0	0
Mar.	3.74	3.55	0	1.66	1.60	0
Apr.	3.85	3.53	0	1.67	1.65	0
May	3.71	3.40	0	1.67	1.60	0
June	4.08	3.85	0	1.81	1.79	3.44
July	3.30	3.11	4.07	1.44	1.49	2.78
Aug.	2.93	2.69	3.52	1.24	1.26	2.40
Sept.	3.48	3.19	4.18	1.47	1.50	2.85
Oct.	3.03	0	3.73	1.31	1.34	2.55
Nov.	3.19	2.95	3.86	1.39	0	2.67
Dec.	3.37	3.15	4.08	1.44	0	2.86

Table 3-4. Relative catchabilities averaged over areas by gear and country.

	Purse Seine	
Gear:	51-150T	151-500T
Month	USSR	SPAIN
Jan.	0	0
Feb.	1.59	1.68
Mar.	0	1.95
Apr.	0	0
May	1.73	1.94
June	1.94	2.17
July	1.57	1.76
Aug.	0	1.48
Sept.	0	1.75
Oct.	0	1.57
Nov.	0	1.67
Dec.	0	0

Table 3-3. Relative catchability averaged over areas by gear and country.

Gear:	Paired Trawl	Longline
	COUNTRY	
Month	Canada	USA
Jan.	0	0.12
Feb.	0	0.08
Mar.	0	0
Apr.	0	0
May	0	0.09
June	0.31	0.10
July	0.25	0.08
Aug.	0.22	0.07
Sept.	0	0.45
Oct.	0	0.07
Nov.	0	0.75
Dec.	0	0.08

Table 4. Effects of extreme values on ranges of monthly relative catchabilities.

Country	Gear Category			(Highest Value Minus Next Highest Value) Range
USA	Other Trawler Side	0-50	T	.41
USA		51-150	T	.40
USA		150-500	T	.40
Canada		150-500	T	.33
USSR		150-500	T	.53
USSR		501-900	T	.43
Poland		501-900	T	.44
USA	Other Trawler Stern	0-50	T	.32
USA		51-150	T	.41
USA		151-500	T	.42
Canada		501-900	T	.32
Poland		901-1800	T	.45
Germany, F.R.		901-1800	T	.76
USSR		1800+	T	.45
Poland		1800+	T	.44
Germany, F.R.		1800+	T	.75
Romania		1800+	T	.24
Japan		1800+	T	.26
Bulgaria		1800+	T	.56
USSR	Purse Seine	51-150	T	.57
Spain	Paired Trawl	151-500	T	.32
USA	Line Trawl	All tonnage		.44
			AVERAGE	.44