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Catch per unit effort in the Faroese prawn fishery (*Pandalus borealis*) in ICNAF Subarea 1, 1975-1977

by

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SUMMARY

The present paper deals with information collected via logbook sheets from prawn trawlers from the Faroe Islands operating off West Greenland in ICNAF Subarea 1. For a description of the logbook system, see Hoydal (1973). The data included in the analysis refer to the years 1975, 1976, and preliminary results for the first nine months of 1977 and includes altogether about 15,000 separate trawl hauls in the West Greenland offshore area.

The statistical method applied is analysis of variance with catch per unit effort (CPUE) as a dependent variable, and ship, date, time of day, and the statistical rectangle as the independent variables. The results from the statistical analysis suggest that a multiplicative model describes the data, but also that a significant part of the variance is left unexplained.

Notation Variables

CPUE	Catch of shrimp (*Pandalus borealis*) in weight (kg) divided by trawl duration in minutes x 60. Dimension is kg x $hour^{-1}$.
S	Factor referring to ship efficiency. Dimension $hour^{-1}$.
D	Factor referring to average over the day density of shrimp stock. Dimension kg.
F	Factor referring to relative abundance over the day [D x F is the abundance index on which the trawl operates.]
ε	Stochastic term.
ℓCPUE, ℓS, ℓD, ℓF, $\ell\varepsilon$	The logarithm to the base E of CPUE, S, D, F, and ε, respectively.
α, β	Coefficients.
N	Stock in numbers.
M^f	Fraction of stock removed by fishing.
M^0	Fraction of stock which die of other causes than fishing.
$E_{r_1 r}$	Fraction of stock in rectangle r which migrate into rectangle r_1.
W_t	Weight of a single specimen at month t.

R_{rt}	Recruitment in numbers at month t.
α_t	AVailability.

Subscripts

s	ship
r	rectangle
h	hour of the day (from 0 to 23)
d	date
m	month
y	year (either 1975, 1976, or 1977)
t	time in months with January 1975 = 1

Data Base

The Faroese prawn trawlers are obliged to keep a logbook on board ship. Each haul should be recorded giving the date, time, and duration of the haul, together with the position (30' latitude x 1° longitude rectangle). The gear type is also recorded (for description, see Hoydal, 1976). The skipper assesses the catch of each haul of each species and records his estimate. Copies of the logbook sheets are transferred to Faroese authorities (Hoydal, 1973). These data form the basis of the present investigation.

Eight Faroese trawlers took part in the fishery in 1975, and 11 in 1976. All vessels have submitted the logbooks together with the actual landings. However, the quality of the information of one ship operating for the first time in 1976 is low and that ship is excluded from the analysis. The logbooks do not make any distinction between a zero catch due to no shrimp available and a wrecked trawl. Any haul with zero catch is therefore excluded. Also excluded is any haul recorded with incomplete information. This leaves the number of recorded hauls to be included in the analysis as given in Table 1.

Precision of Information

Catch	The skippers are requested to give estimates of the catches in units of 100 kg. The overall average catch per haul is about 500 kg. The best possible information will consequently be subject to uncertainty of 1/2 x 100/500 x 100% = 10% due to the recording of the catches in units of 100 kg.
Effort	The logbook requests the skippers to state duration of haul in units of minutes. However, a unit of a quarter of an hour is used in practice. Average duration of haul is about 100 minutes and the recording will be uncertain by at the very best 1/x x 15/100 x 100% = 8%.
Catch per unit effort	The calculated catch per unit effort (CPUE) thus is borne with an uncertainty of at least 18%.

Definition of Cells

The data collected allow the following cell definition in the analysis of variance, by

- rectangle
- day
- hour of the day
- depth to the bottom when the trawl starts fishing
- fishing vessel.

In principle, the gear could be added to the list but only one gear is actually used, a shrimp trawl.

The rectangles can be grouped into Subareas which was done in some analyses. For all analyses, the month has been used as the finest breakdown of time of the year instead of the date.

Theory

The data were investigated applying analysis of variance (Rao, 1965). The actual computer program applied was the routine "GLM" of SAS-76, Barr *et al.* (1976) implemented on an IBM 370/165 situated at the Danish Technical High School of Copenhagen.

The Models

The models investigated are all of the following type:

CPUE = S x D x F x ε

reformulated as

ℓCPUE = < intercept > + ℓS + ℓD + ℓF + ℓε

(For explanation of the symbols, please consult the notation section.)

The alternative model type

CPUE = S + D + F + ε

was considered early in the project, but was rejected due to considerable smaller explanation of the variance compared to the multiplicative type of model. This applies to all cases when a specific version of the additive and multiplicative model both were fitted to the data.

Diurnal Variation in CPUE (F)

Both Smidt (1976) and Horsted (1976) present curves of diurnal variation of CPUE. The curves are characteristic by a rather irregular pattern with a marked higher level of CPUE from around 11:00 AM to late in the afternoon. This effect in the Faroese data was first investigated by the following model:

1) $\ell CPUE = \ell S_s + \ell D_r + \ell F_h + \ell \varepsilon$

which was applied to the 1975 data for Div. 1B, 1C, 1D, and 1E separately for each month. The results of ℓF_h for May and August 1975 are shown in Fig. 1. The figure suggests a fairly symmetric variation with a peak around noon. Consequently, the model was modified to:

2) $\ell F_h = \alpha \cos \frac{2\pi}{24} h + \beta \cos \frac{4\pi}{24} h.$

Terms containing $\sin \frac{\pi}{24} h$ and $\sin \frac{2\pi}{24} h$ were also fitted, but did not contribute significantly (on a 5% significance level) to explanation of the variance.

The modification substituted to equation (1) giving the modified model

3) $\ell CPUE = \ell S_s + \ell D_{ymr} + \alpha_{ym} \cos \frac{2\pi}{24} h + \beta_{ym} \cos \frac{4\pi}{24} h + \ell \varepsilon$

which was fitted for each Subarea separately.

The analysis of variance schemes are found in Table 2, and the diurnal variations estimated by the model for May and August 1975, Div. 1B, are shown as curves in Fig. 2.

Relative Abundance by Month and by Rectangle

The factor D_{ymr} is the relative abundance averaged over the day. That is the abundance measured, if trawling was started at midnight and concluded 24 hours later. The factor is estimated directly from the model (Equation 3) which is fitted for each group of rectangles forming a subarea. The analysis of variance scheme is found in Table 2. The fitted parameters are given in Table 3. The analysis of variance schemes gives correlation coefficients in the range 0.39 to 0.62. This means that only 39% to 62% of the total variation around the intercept has been explained applying the model above. Inspection of residuals reveals no obvious trends, neither in diurnal variation nor as a trend over the time series. The model has consequently no obvious extension.

The next step is to combine the D_{ymr}'s for each subarea into an index of stock density which may be applied to that subarea. This can be done as follows:

1. The D_{ymr}'s are averaged over the fished rectangles.

2. The D_{ymr}'s are summed over the fished rectangles.

3. Each trawl is handled as a random sample representing the entire stock in that subarea. The model then becomes

$$\ell CPUE = \ell S_s + \ell D_{yma} + \alpha_{yma} \cos \frac{2\pi}{24} h + \beta_{yma} \cos \frac{2\pi}{24} h + \ell \varepsilon.$$

The choice between the three above-mentioned indices should be based on the biological evidence available. If the Faroese prawn trawlers exploit the entire stock at any monent, procedure 2 would be applicable, while either procedure 1 or 3 apply when the Faroese fleet is only exploiting part of the stock at any moment.

The assumption underlying procedure 3, no density differences between rectangles within a given month and subarea, has been tested with the 1975 data. The result is given in Table 4. It appears from Table 4 that the assumption is invalid at least in April-May and September-October in Div. 1B. As the overwhelming part of the fishery takes place in Div. 1B, procedure 3 does not seem justified.

The Faroese fishery does not seem to exploit the entire stock at any moment, and procedure 1 is consequently to be preferred to procedure 3. The calculated stock density indices month by month for Div. 1B and 1D can be found in Table 5.

The two other divisions have been left out due to the difficulties with the internal normalization. These indices have been plotted in Fig. 3 as a time series for the two divisions.

The indices by rectangles, coming out in the 3 years treated, calculated as the antilog of (<intercept + D_{ymr}) are plotted out on charts in Fig. 4.

Relative Efficiency of Trawlers

The factors S_s is estimated from the model (3) and the results can be found in Table 2 (analysis of variance scheme) and Table 3 (estimated coefficients). Even though every normalization has been done, one trawler (8307) large differences in efficiency between the same trawler operating in different subareas can be observed in Table 3. The reason for this is not known and calls for care when interpreting the results.

Discussion

Interpretation of the stock density indices can be done in the light of the general model:

$$N_{rt+1} = N_{rt}\,[1 - M_t^f - M_t^0 - \sum_{r_1} E_{r_1 r}(t)] + \sum_{r_1} N_{r_1 t}\, E_{r r_1}(t) + R_{rt}$$

$$CPUE_{rt} = \alpha_t W_t N_{rt}$$

The model points out several weaknesses of the calculated stock densities. First - changes in the number of shrimps per kg over the fishing season are ignored due to lack of information. Second - even though grouping the information into divisions tends to diminish the influence of migration, it is an unknown parameter in any interpretation. Third - recruitment to the fishable stock will influence the average number of shrimps per kg in the catch as well as the actual number of shrimps in the stock. Fourth - the availability α_t may change during the fishing season.

Even with the treatment of these large data base limitations in the information taken from catch-effort data are evident.

This point has a severe bearing on the usefulness of any survey data also.

The exercise should, however, be a useful supplement to and correction of the "swept area" method based on raw CPUE data used, e.g. by Ulltang and Øynes (1976) and Hoydal (1976).

It is suggested to be a worthwhile exercise to try to plot these calculated indices in Table 5 against cumulative effort (see Ricker, 1975, p. 153-154).

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TABLE 1. Number of recorded hauls by month and Subarea included in the analyses.

	Division			
Month	1B*	1C	1D	1E
January	8 296 630	- 153 12	371 247 -	3 - -
February	- 220 256	37 58 221	287 98 107	- - -
March	- - 303	31 24 217	276 194 51	14 - -
April	262 406 688	15 60 -	57 232 3	5 10 8
May	701 1147 919	28 - -	- 4 -	- - -
June	376 1131 766	221 3 93	153 47 30	12 - -
July	- 861 690	8 11 141	220 100 68	314 - -
August	361 787 343	1 - -	94 - -	27 - -
September	240 450 34	77 - -	165 - -	3 23 -
October	557 511 -	- - -	53 - -	44 - -
November	458 832 -	- 9 -	- 111 -	- - -
December	402 508 -	29 6 -	- - -	- - -

* The three entries in each row refer to 1975, 1976, 1977 respectively.

Table 2. Analysis of variance scheme for the model

$$\ell\text{CPUE} = < \text{intercept} > + \ell S_s + \ell D_{rym} + \alpha_{ym} \cos \frac{2\pi}{24} h + \beta_{ym} \cos \frac{4\pi}{24} h$$

applied for each Div. 1B, 1C, 1C, and 1E. The null hypothesis is ℓCPUE = < intercept >. The type I SS is the so-called sequential test, that is, a test that the x2 term (cos $\frac{2\pi}{24}$ h) contributes to the explanation of the variance if BAADNO (trawler efficiency) and RECT (D_{rym}) already have been taken into account. The type IV SS is testing the reduction in sum of squares due to that effect given all other effects. For details see Barr *et al.* (1976).

Explanation of terms:		
	BAADNO	Ship number (code), ℓSx
	RECT (AAR*MDR)	D_{rym}
	x2 (AAR*MDR)	$\alpha_{ym} \cos \frac{2\pi}{24} h$
	x4 (AAR*MDR)	$\beta_{ym} \cos \frac{4\pi}{24} h$

DIV. 1B

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

MAINAREA=202

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LCPUE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	231	4574.66442018	19.80374208
ERROR	14911	7174.99839217	0.48118828
CORRECTED TOTAL	15142	11749.66281235	

	F VALUE	PR > F	R-SQUARE	C.V.
Model	41.16	0.0001	0.389344	11.5365
		STD DEV		LCPUE MEAN
		0.69367736		6.01290843

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BAADNO	11	473.34249290	89.43	0.0001
RECT(AAR*MDR)	162	3569.16864524	45.79	0.0001
X2(AAR*MDR)	29	440.93038284	31.60	0.0001
X4(AAR*MDR)	29	91.22289920	6.54	0.0001

	DF	TYPE IV SS	F VALUE	PR > F
BAADNO	11	531.89901086	100.49	0.0001
RECT	162	3208.53162018	41.16	0.0001
X2	29	465.85707434	33.38	0.0001
X4	29	91.22289920	6.54	0.0001

Table 2. continued

Div. 1C

STATISTICAL ANALYSIS SYSTEM
MAINAREA=203

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LCPUE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	97	376.63249209	3.88280920
ERROR	1360	461.50774485	0.33934393
CORRECTED TOTAL	1457	838.14023693	

Model

F VALUE	PR > F	R-SQUARE	C.V.
11.44	0.0001	0.449367	10.5589
	STD DEV		LCPUE MEAN
	0.58253234		5.51699772

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BAADNO	11	73.69523315	19.74	0.0001
RECT(AAF*MDR)	43	268.73362731	18.42	0.0001
X2(AAF*MDR)	22	26.21954883	3.51	0.0001
X4(AAF*MDR)	21	7.98408279	1.12	0.3182

	DF	TYPE IV SS	F VALUE	PR > F
BAADNO	8	32.79637976	12.08	0.0001
RECT	41	259.60282484	18.66	0.0001
X2	21	26.17079843	3.67	0.0001
X4	21	7.98408279	1.12	0.3182

Div. 1D

STATISTICAL ANALYSIS SYSTEM
MAINAREA=204

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LCPUE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	148	623.41265882	4.21224769
ERROR	2819	1008.28331876	0.35767411
CORRECTED TOTAL	2967	1631.69597758	

MODEL

F VALUE	PR > F	R-SQUARE	C.V.
11.78	0.0001	0.382064	11.3730
	STD DEV		LCPUE MEAN
	0.59805862		5.25856451

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BAADNO	10	224.26856558	62.70	0.0001
RECT(AAF*MDR)	94	333.65489903	9.93	0.0001
X2(AAF*MDR)	22	55.26617976	7.02	0.0001
X4(AAF*MDR)	22	10.18261445	1.29	0.1620

	DF	TYPE IV SS	F VALUE	PR > F
BAADNO	10	108.73125585	30.40	0.0001
RECT	94	341.56435523	10.16	0.0001
X2	22	51.64005081	6.56	0.0001
X4	22	10.18261445	1.29	0.1620

Table 2. continued

Div. 1E

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M
MAINAREA=205

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LCPUE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	38	144.92534856	3.81382496
ERROR	421	88.57075390	0.21038184
CORRECTED TOTAL	459	233.49610246	

	F VALUE	PR > F	R-SQUARE	C.V.
Model	18.13	0.0001	0.620676	8.2011

STD DEV	LCPUE MEAN
0.45867400	5.59281562

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BAADNO	4	96.36372123	114.51	0.0001
RECT(AAR*MDR)	13	44.01941553	16.10	0.0001
X2(AAR*MDR)	11	2.18827474	0.95	0.4967
X4(AAR*MDR)	10	2.35393707	1.12	0.3462

	DF	TYPE IV SS	F VALUE	PR > F
BAADNO	1	15.78219908	75.02	0.0001
RECT	12	40.93250122	16.21	0.0001
X2	10	2.33783765	1.11	0.3519
X4	10	2.35393707	1.12	0.3462

Table 3. Estimated parameters in the model

$$\ell CPUE = \text{< intercept >} + \ell S_s + \ell D_{rym} + \alpha_{ym} \cos \frac{2\pi}{24} h + \beta_{ym} \cos \frac{4\pi}{24} h + \ell \varepsilon$$

for each Div. 1B, 1C, 1D, and 1E. The fitted values correspond to the analysis of variance schemes given in Table 2. The B after a parameter signifies that a normalization has taken place. The normalizations are:

ℓS_{8307}	= 0	
$\ell D_{205058,77,9}$	= 0	Division 1B
$\ell D_{209055,77,7}$	= 0	Division 1C
$\ell D_{210054,77,7}$	= 0	Division 1D
$\ell D_{218055,77,4}$	= 0	Division 1E

plus extras in Div. 1C and 1E. These extras make interpretation difficult for these two Divisions.

Intercept and ℓS (ship's efficiency) are given. Stock indices are given in the charts of Fig. 4 and Table 5 and examples of the diurnal variation in Fig. 2.

Div. 1B

PARAMETER		ESTIMATE		STD ERROR OF ESTIMATE
INTERCEPT		4.90092022	B	0.13015796
BAADNO	2060	0.26952845	B	0.04504042
	2543	-0.20353478	B	0.03686357
	2574	1.43878254	B	0.29198173
	2800	0.47110098	B	0.03779756
	3392	0.28135929	B	0.14052275
	3717	0.79014210	B	0.04573452
	6123	0.39051336	B	0.04149244
	6141	-0.04309359	B	0.03588195
	7057	0.22350510	B	0.03177095
	7065	0.46592926	B	0.03694274
	7165	0.58157845	B	0.04435539
	8307	0.00000000	B	•

Div. 1C

PARAMETER		ESTIMATE		STD ERROR OF ESTIMATE
INTERCEPT		4.93293859	B	0.20044208
BAADNC	2060	1.31098332	B	0.31761304
	2543	0.64434961	B	0.18987971
	2574	0.56878446	B	0.47047564
	2800	1.60529395	B	0.34164453
	6123	1.32350816	B	0.32806303
	6141	1.43215468	B	0.40584986
	6163	-0.38981940	B	0.35507280
	6487	1.00147490	B	0.43374196
	7057	2.00568995	B	0.26870489
	7065	2.71873893	B	0.51985954
	7165	2.51895908	B	0.31581686
	8307	0.00000000	B	•

Div. 1D

PARAMETER		ESTIMATE		STD ERROR OF ESTIMATE
INTERCEPT		5.07451878	B	0.07269745
BAADNC	2060	0.85027715	B	0.35958684
	2543	-0.39267778	B	0.07594256
	3392	-0.54230874	B	0.17113814
	6123	0.37390775	B	0.10437003
	6141	0.25539495	B	0.08373788
	6163	-0.45450965	B	0.11665470
	6487	-0.66837328	B	0.10036749
	7057	0.23279471	B	0.08864830
	7065	0.42381689	B	0.17124617
	7165	0.24272699	B	0.15318473
	8307	0.00000000	B	•

Div. 1E

PARAMETER		ESTIMATE		STD ERROR OF ESTIMATE
INTERCEPT		4.55517899	B	0.14554817
BAADNC	2060	0.35902812	B	0.17468233
	2543	1.38347864	B	0.23219062
	6487	-1.39224740	B	4.94004805
	7057	2.06078239	B	0.21862600
	8307	0.00000000	B	•

Table 4. Testing identity of stock density between rectangles in 1975 within a given month and subarea.

	1975							
	1B		1C		1D		1F	
Month	No. of rect.	P	No. of rect.	P	No. of rect.	P	No. of rect.	P
Jan	1	-	0	-	6	0.0001	1	-
Feb	0	-	3	0.8715	8	0.0002	0	-
Mar	0	-	1	-	7	0.0001	1	-
Apr	4	0.0206	1	-	4	0.1139	1	-
May	6	0.0001	2	0.6146	0	-	0	-
June	3	0.2792	6	0.0001	5	0.0736	2	-[a]
July	0	-	1	-	5	0.0484	2	-[a]
Aug	4	0.1189	1	-	5	0.8728	2	0.1912
Sep	6	0.0203	3	0.0449	5	0.0456	1	-
Oct	5	0.0001	1	-	4	0.0001	4	0.0163
Nov	2	0.7752	0	-	0	-	0	-
Dec	5	0.2158	1	-	0	-	0	-

[a] Cannot be compared.

The test is an F-test in the model $\ell CPUE = \ell S_s + \ell F_h + \ell D_r$ fitted for each subarea, year and month. The figure is prob $(\ell D_r = 0 \mid \ell S_s, \ell F_h)$ · 0.0001 means ≤0.0001 - means that either no fishery took place or only one rectangle was exploited.

Table 5. Indices of stock density for Div. 1B and 1D calculated from Table 3 by averaging over all fished rectangles in the division by month.

	1975				1976				1977[a]			
	1B		1D		1B		1D		1B		1D	
Month	No. of rect.	Index	No. of rect.	Index	No. of rect.	Index	No. of rect.	Index	No. of rect.	Index	No. of rect.	Index
Jan	1	1.53	6	0.09	4	0.73	5	-0.06	7	0.78	0	-
Feb	0	-	8	0.12	3	1.51	4	-0.16	6	0.82	2	0.12
Mar	0	-	7	0.36	0	-	6	0.11	3	1.17	5	-0.32
Apr	4	1.19	5	0.33	5	1.33	9	-0.13	5	0.73	1	-0.20
May	6	1.24	0	-	9	1.54	2	-0.86	12	0.25	0	-
June	4	0.97	5	-0.12	6	1.07	2	-0.44	12	0.75	2	-0.05
July	0	-	5	0.06	6	0.68	2	0.07	8	0.82	0	-
Aug	4	0.50	5	-0.29	5	0.88	0	-	7	0.27	0	-
Sep	6	-0.01	5	-0.68	5	0.20	0	-				
Oct	5	0.88	4	-0.19	5	0.37	0	-				
Nov	4	0.82	0	-	9	0.31	4	0.21				
Dec	5	0.61	0	-	7	0.27	0	-				

[a] Provisional.

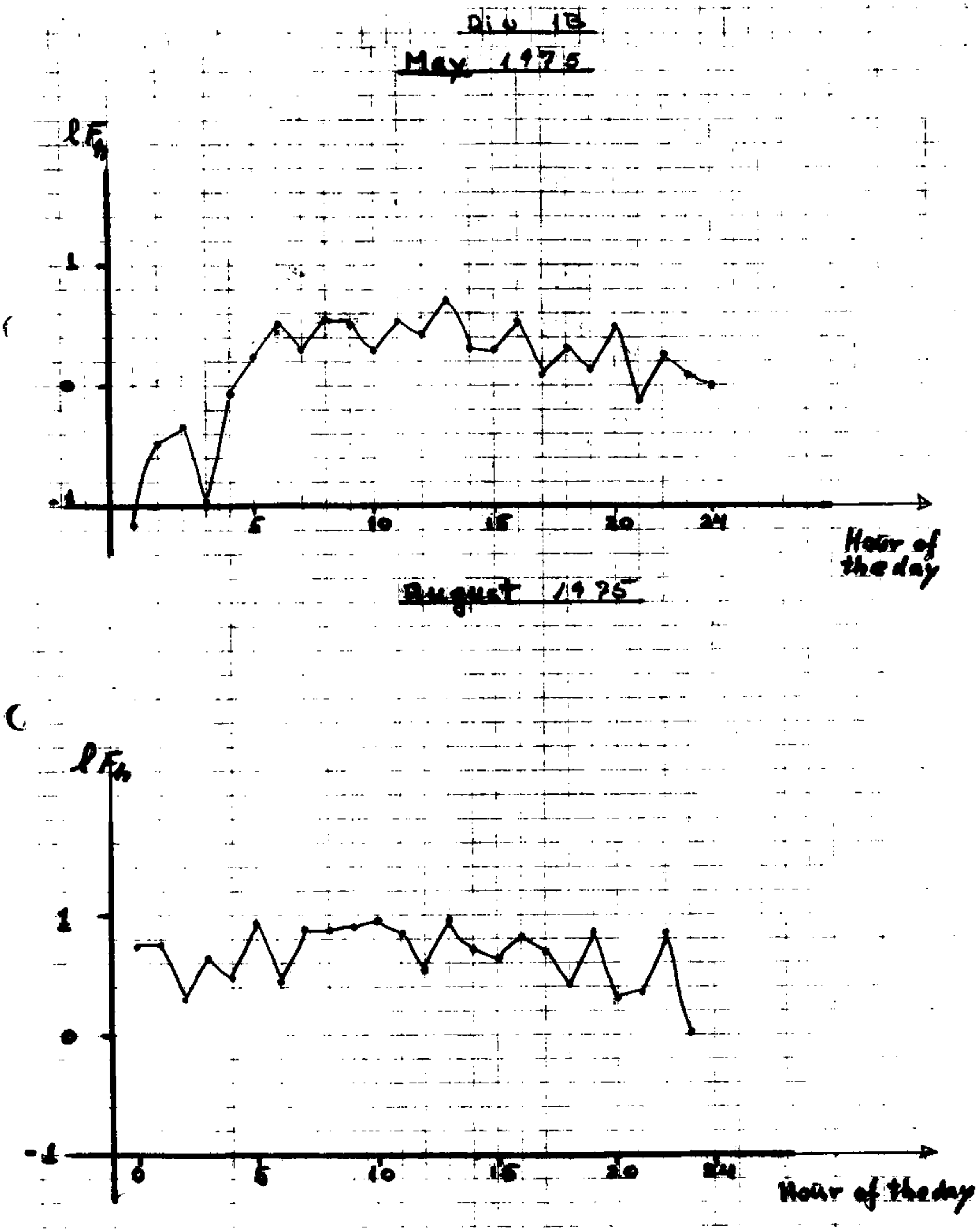

Fig. 1. Diurnal variation in $\log_e$ CPUE as fitted by the model

$\ell CPUE = \ell S_s + \ell D_r + \ell F_h + \ell \varepsilon$.

Fig. 2 to follow as an Addendum to this document

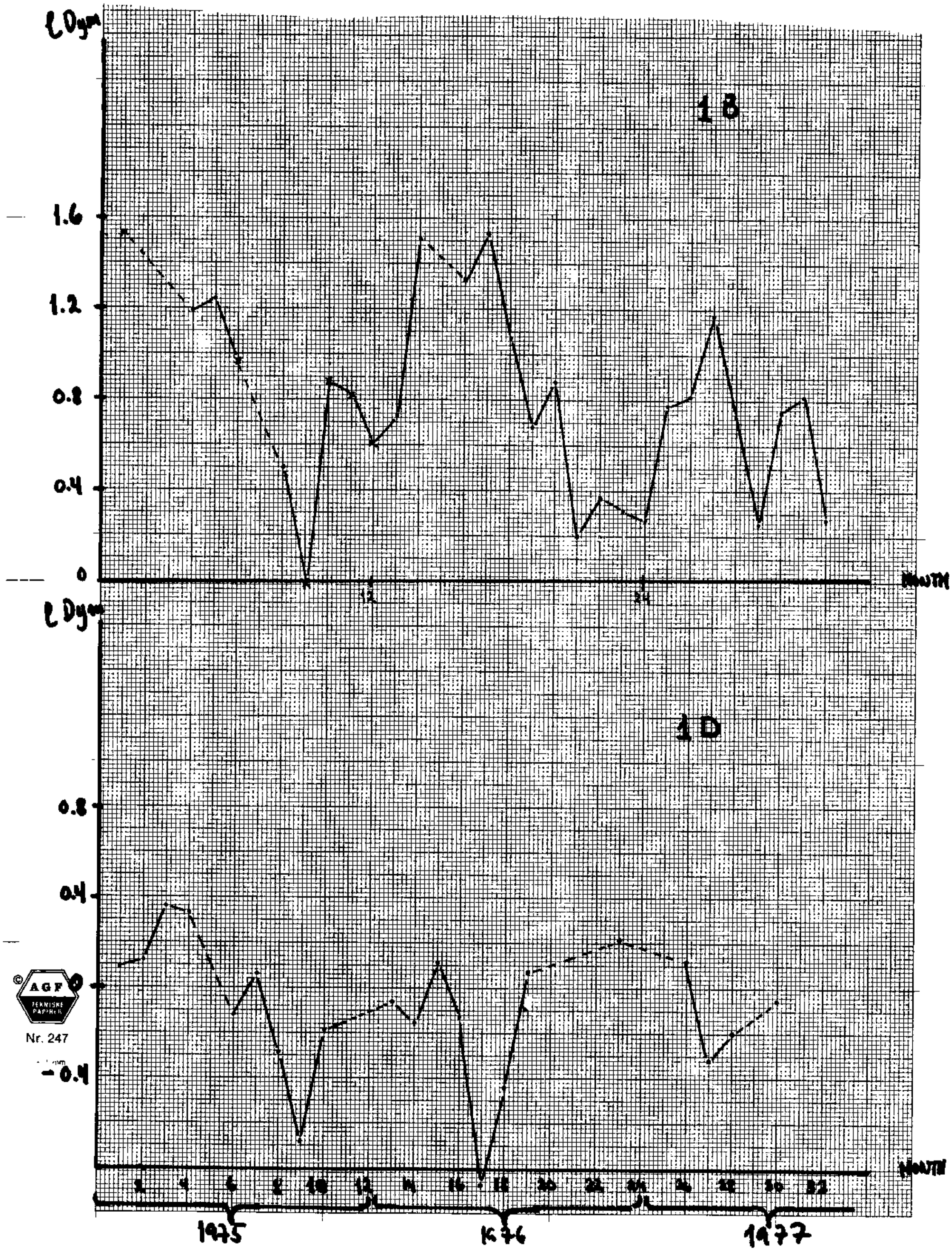

Fig. 3. Stock density estimates for Div. 1B and 1D against time.

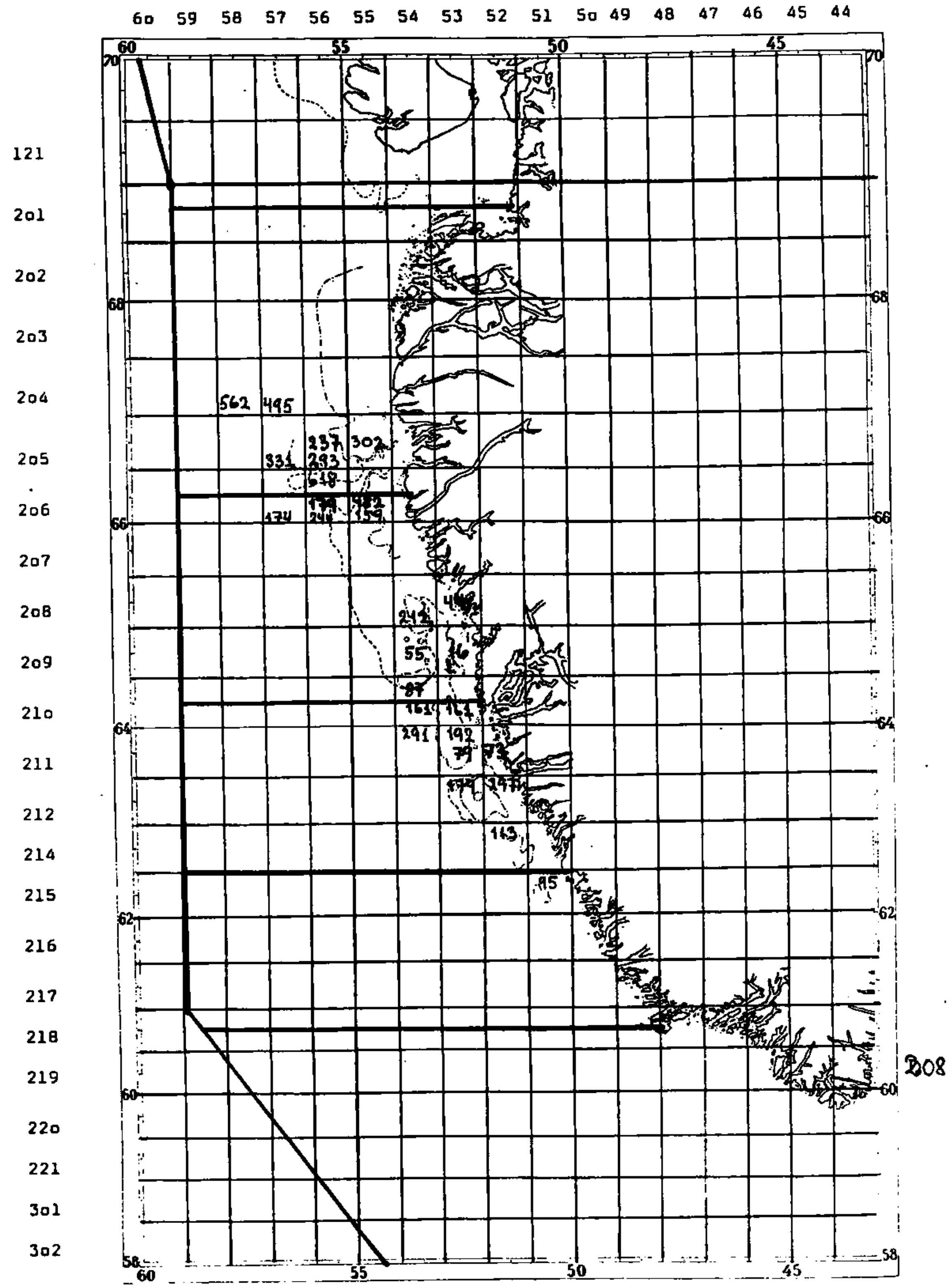

Fig. 4. CPUE estimated from model as intercept + index for rectangle.
January - 1975, 1976, and 1977.

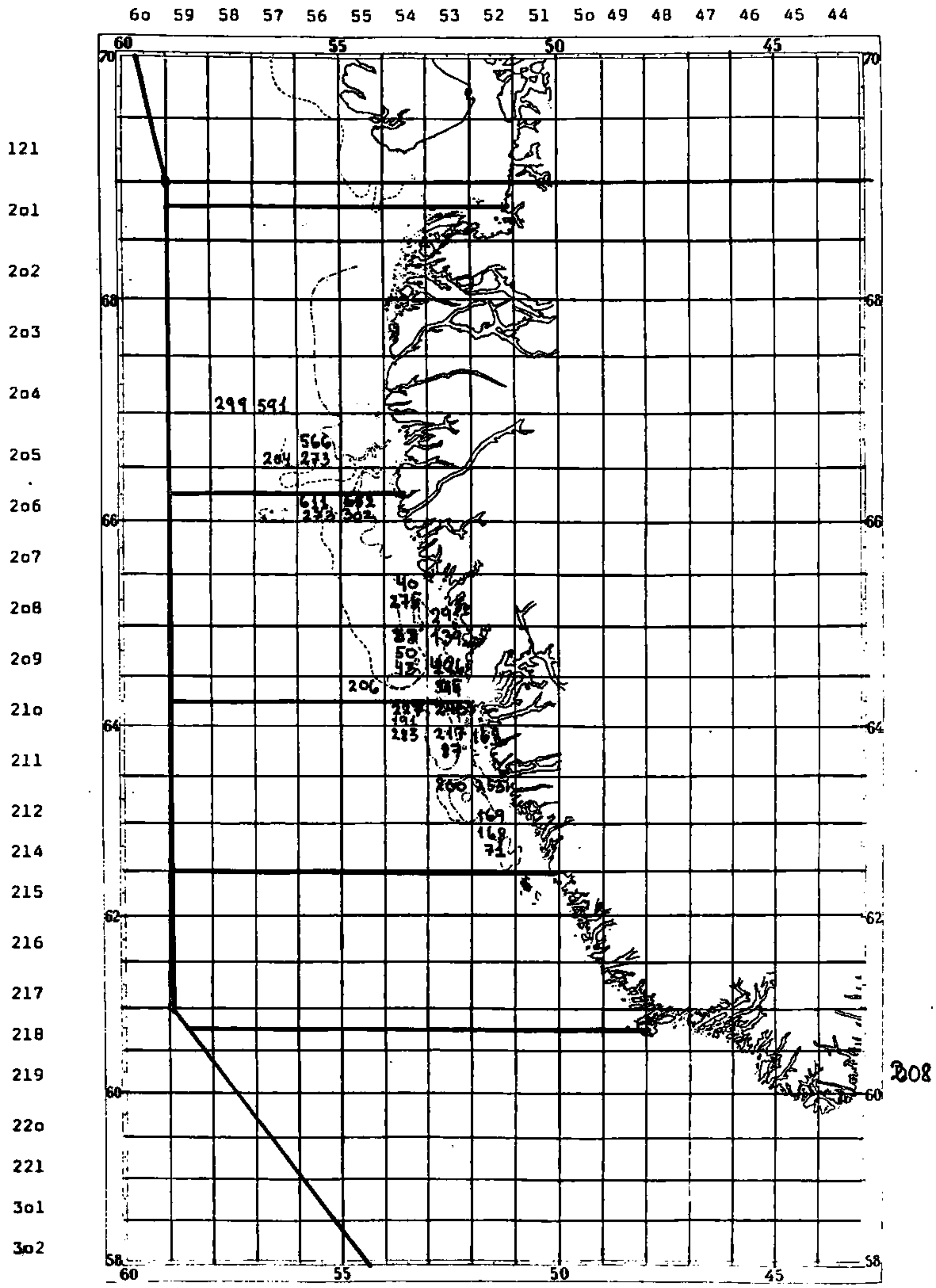

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. February - 1975, 1976, and 1977.

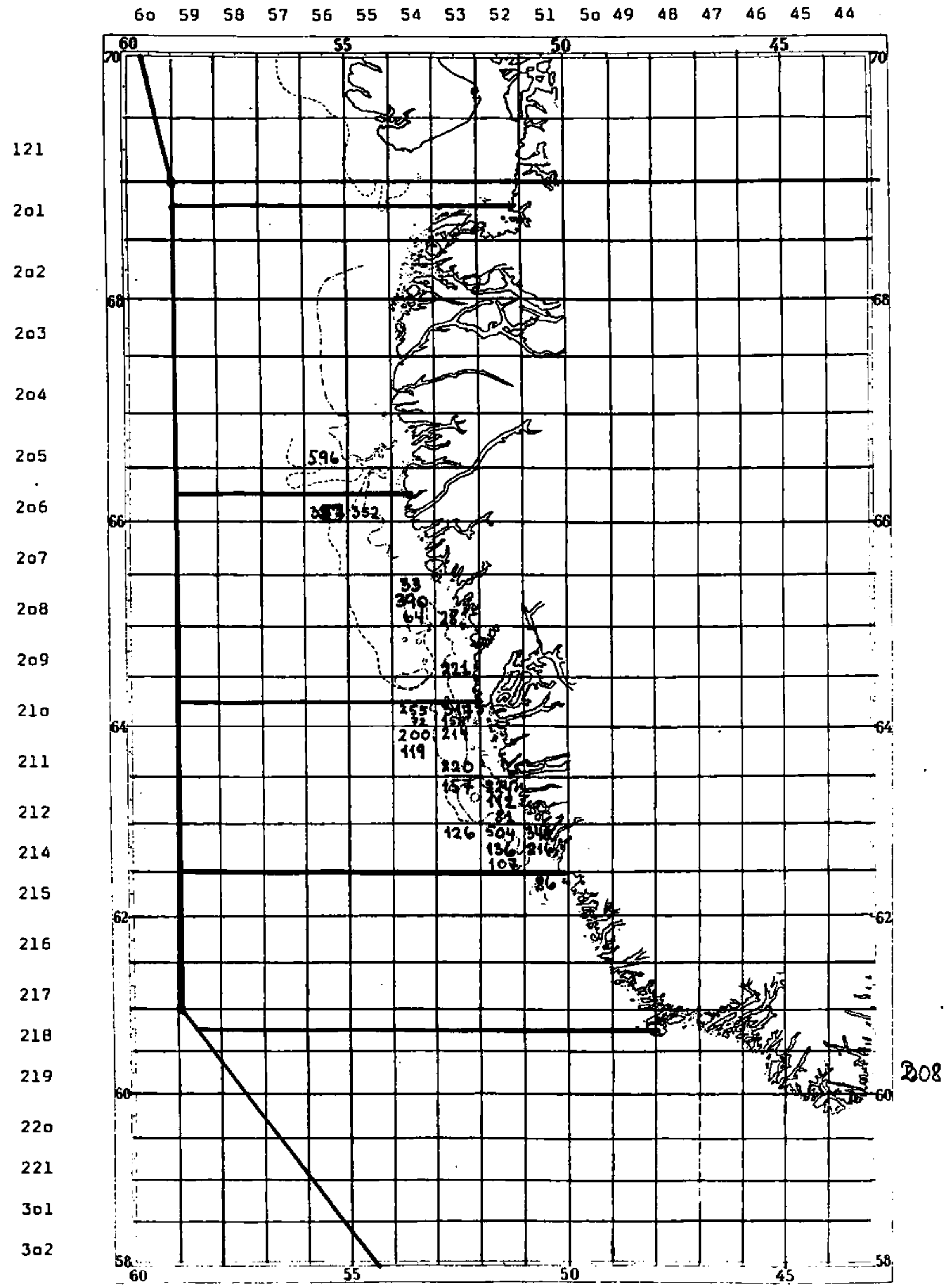

Fig. 4. CPUE estimated from model as intercept + index of rectangle.
continued <u>March</u> - 1975, 1976, and 1977.

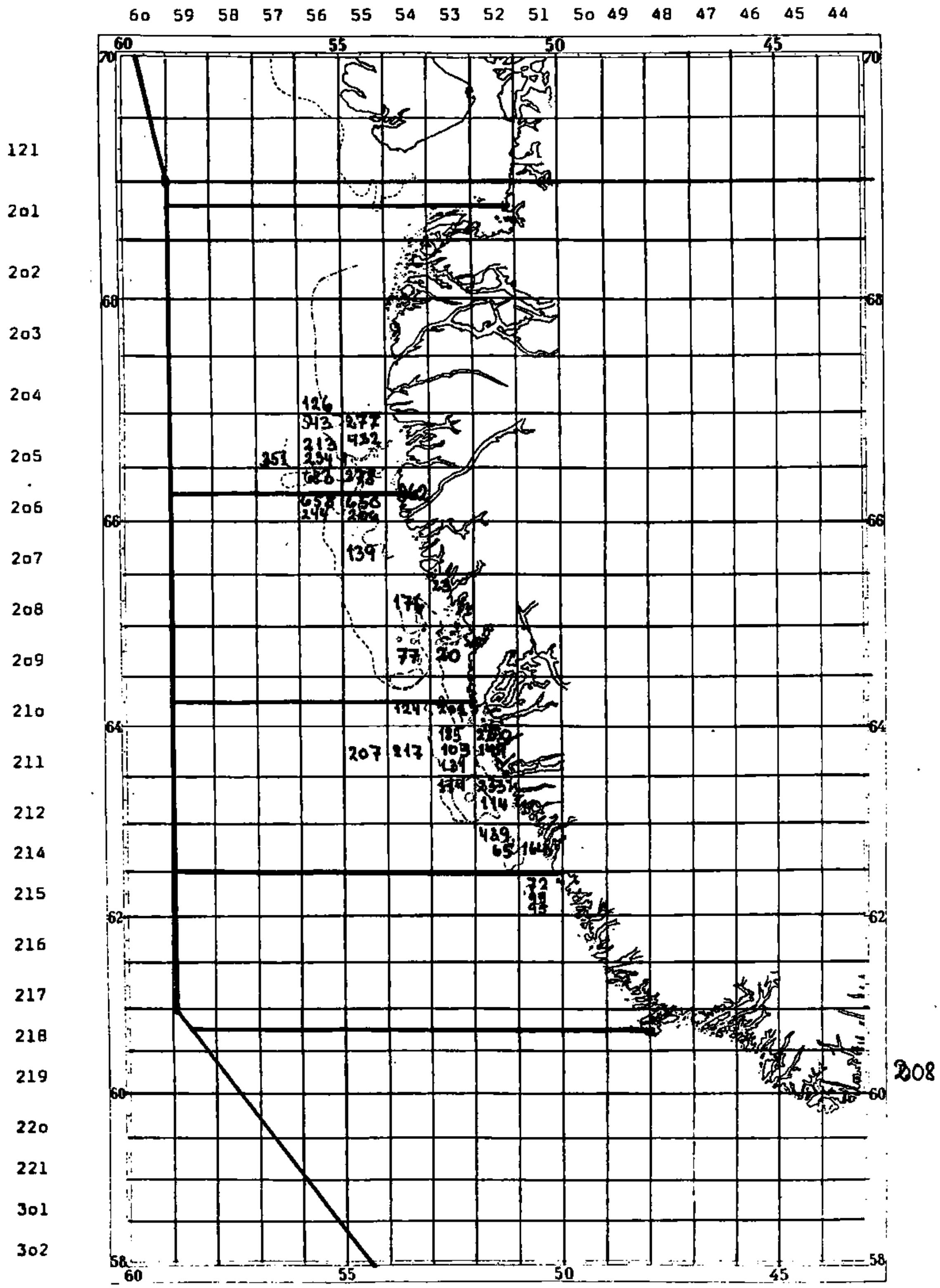

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. April - 1975, 1976, and 1977.

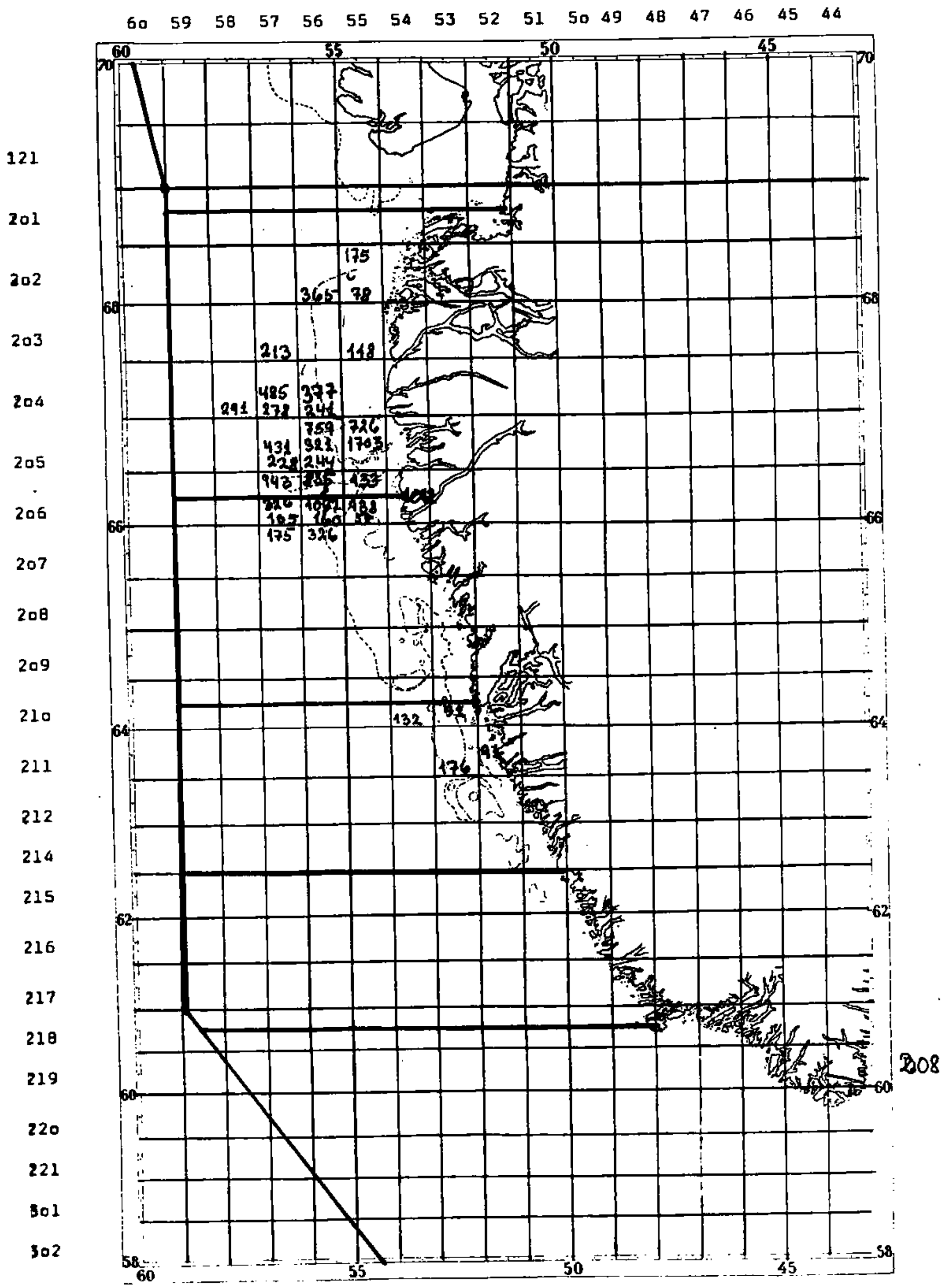

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. May - 1975, 1976, and 1977.

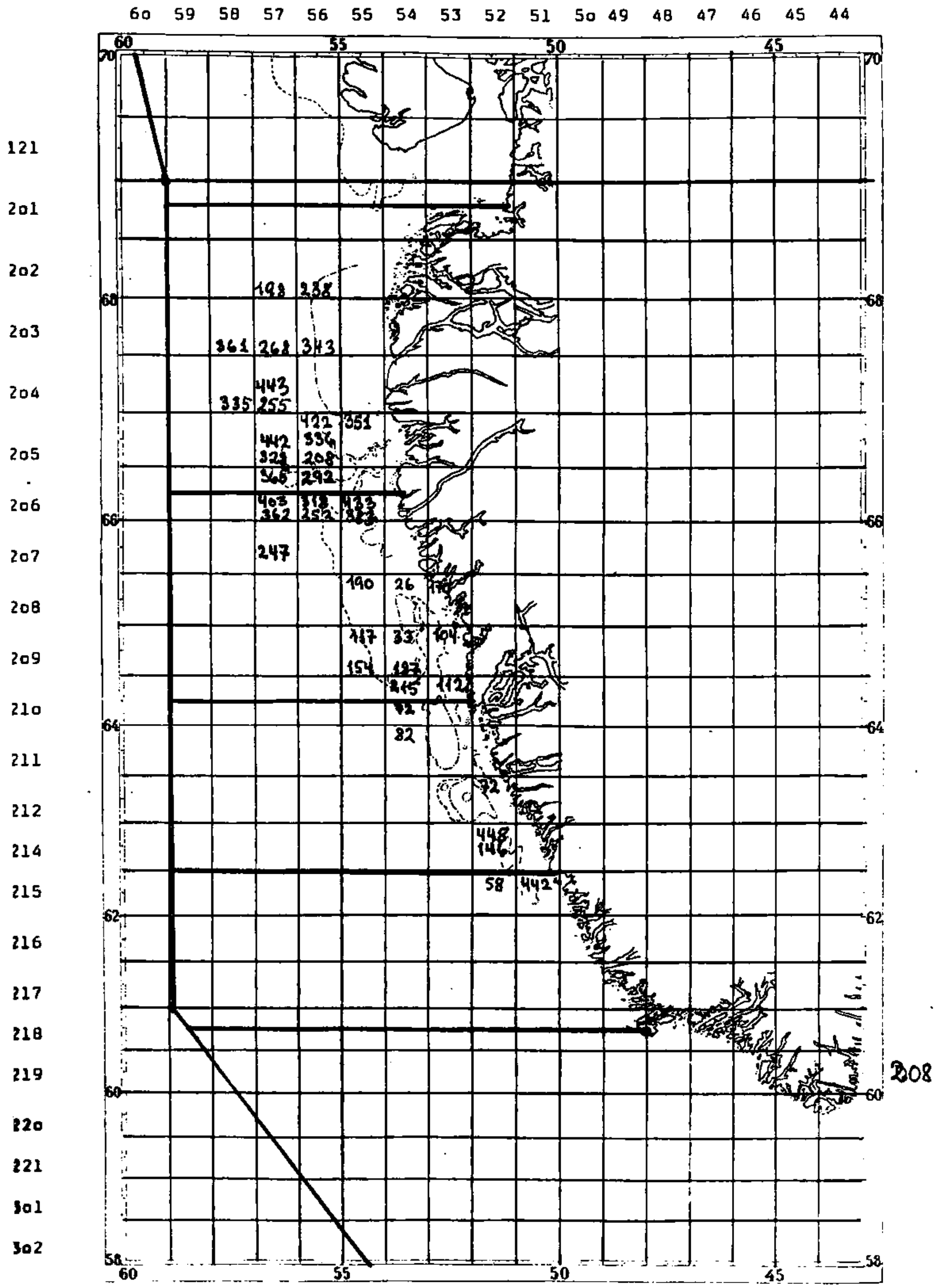

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. June - 1975, 1976, and 1977.

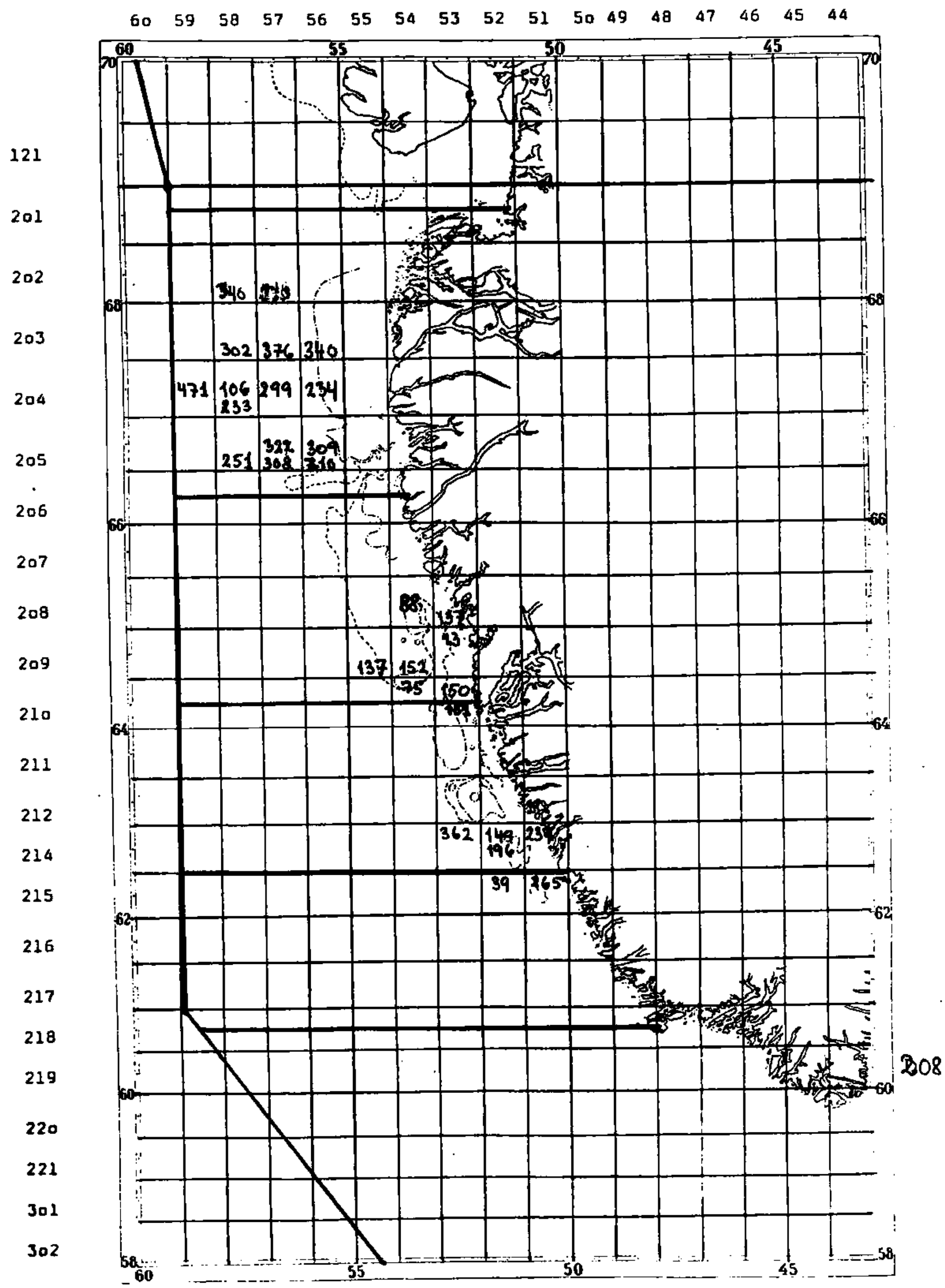

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. July - 1975, 1976, and 1977.

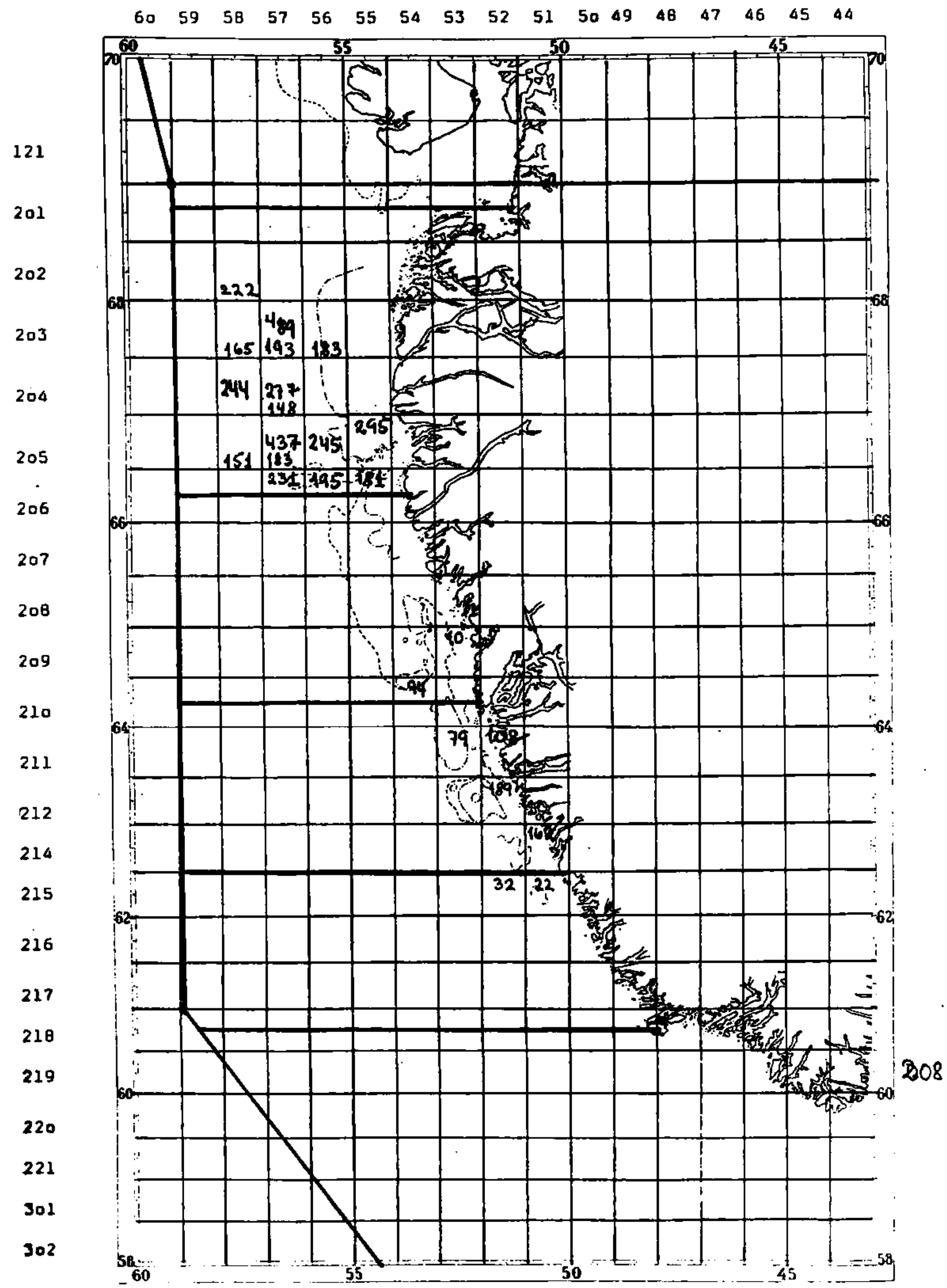

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. August - 1975, 1976, and 1977.

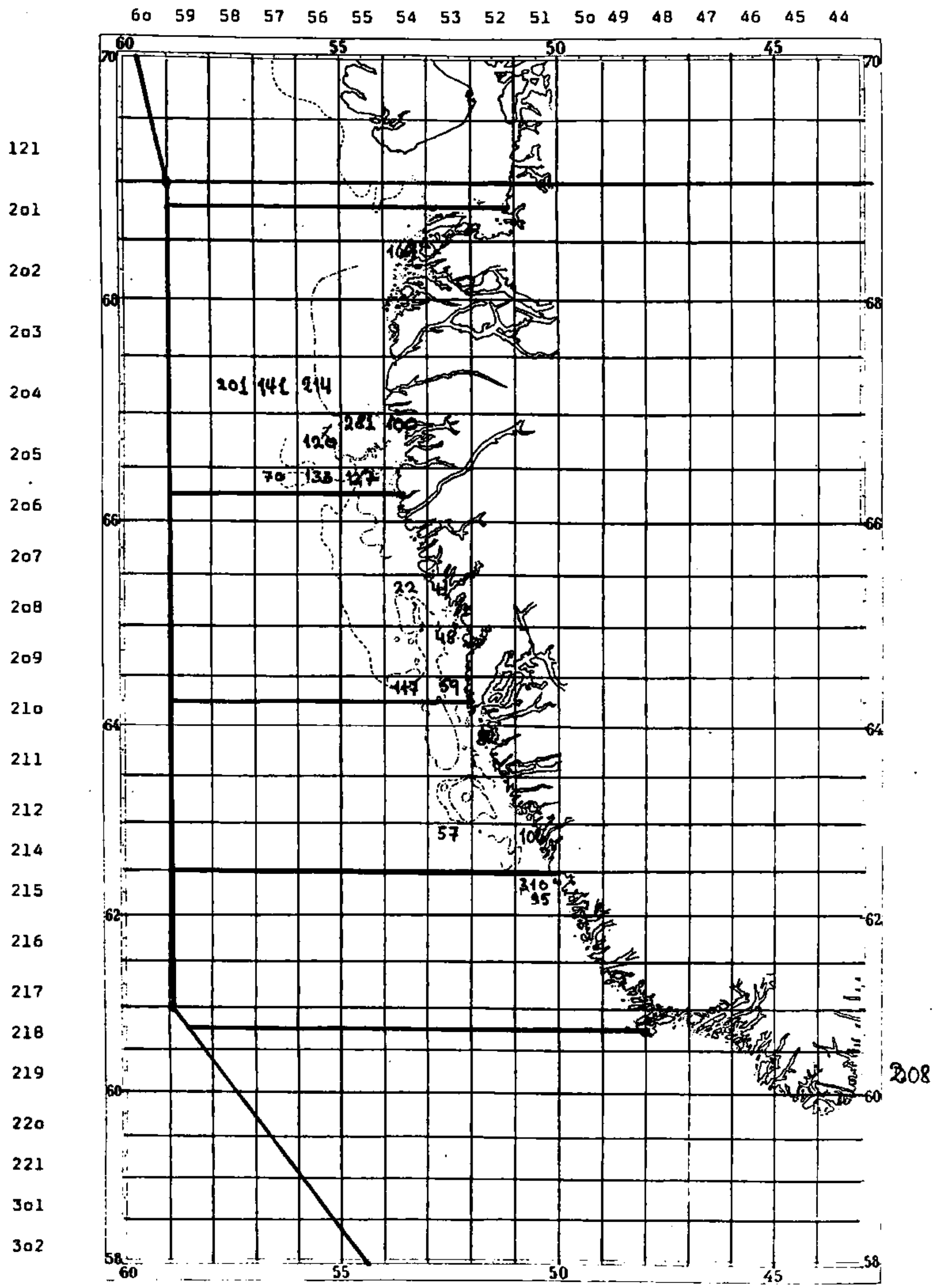

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. September - 1975, 1976, and 1977.

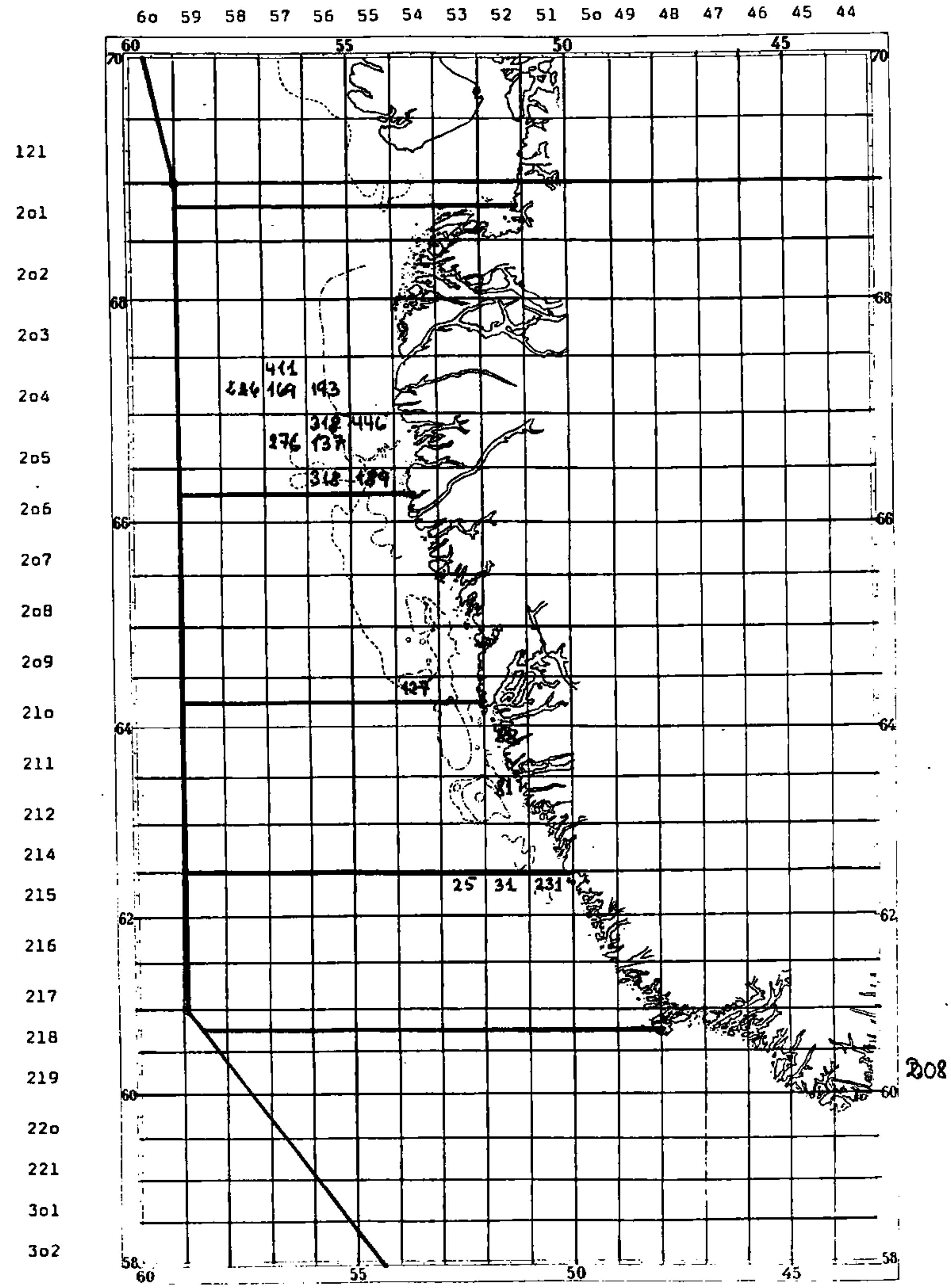

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle.
October - 1975, 1976, and 1977.

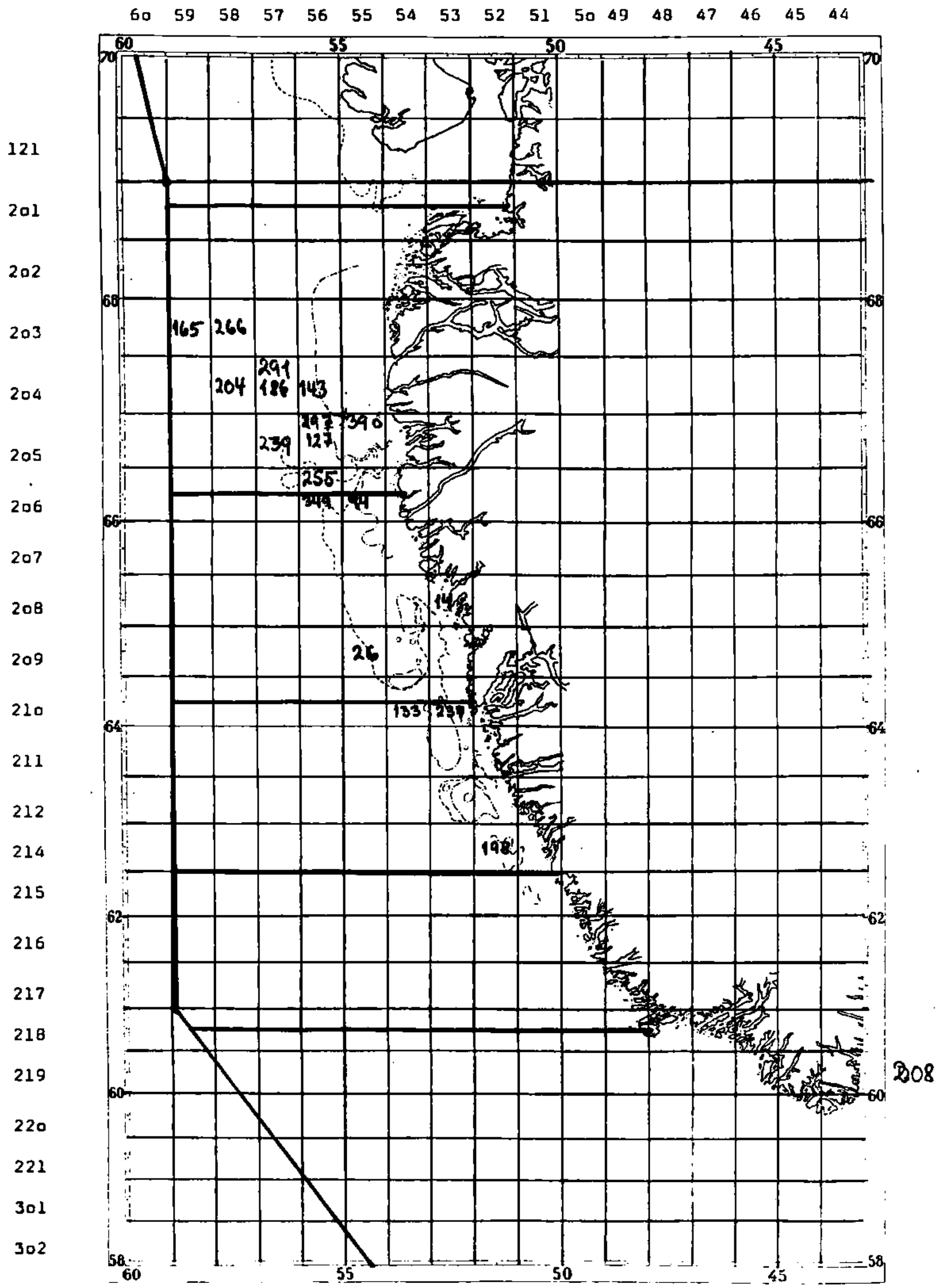

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. November - 1975, 1976, and 1977.

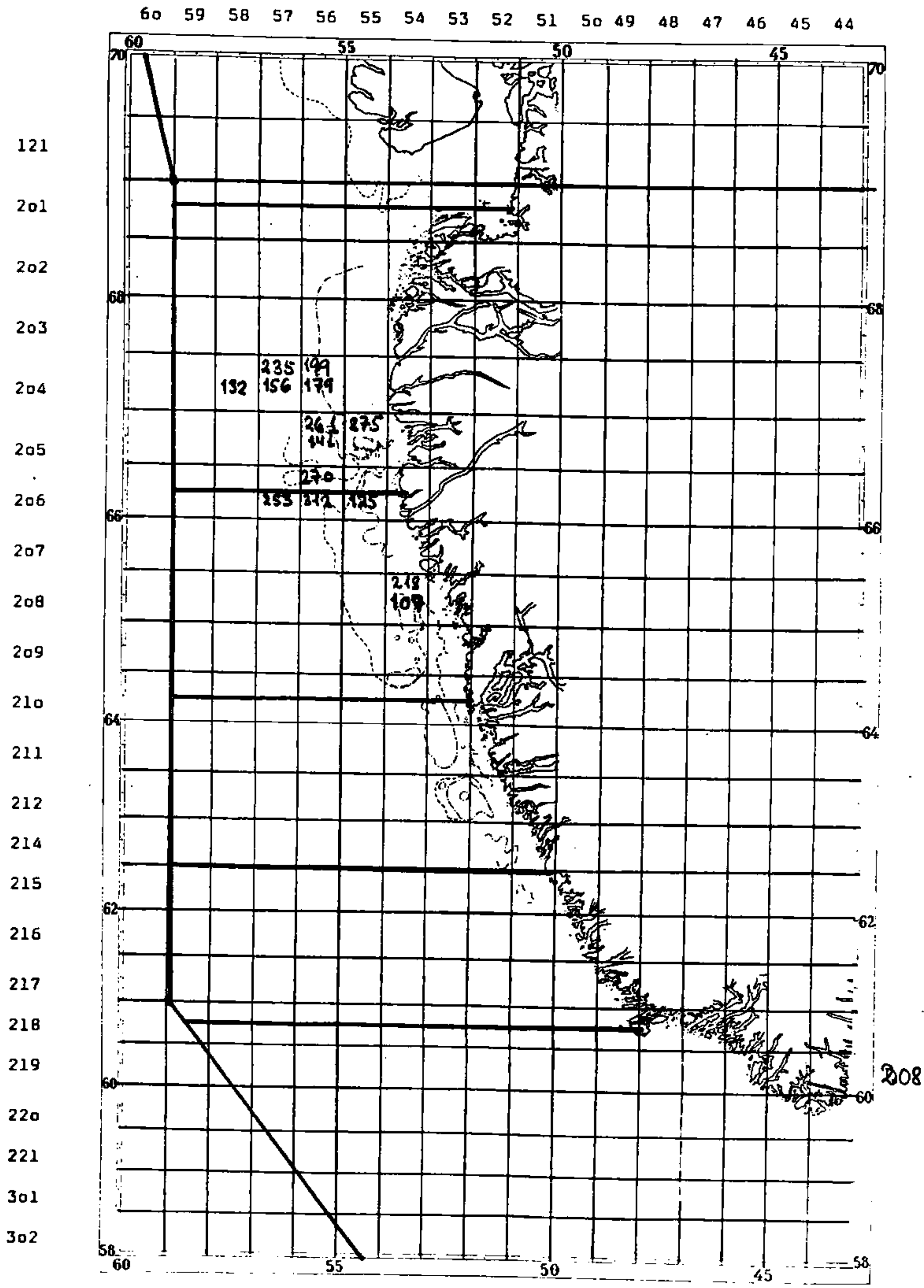

Fig. 4. continued CPUE estimated from model as intercept + index for rectangle. December - 1975, 1976, and 1977.